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Provided are physical science laboratory experiments which have been developed and used as a part of an experimental one year undergraduate course in general science for non-science majors. The experiments cover a limited number of topics representative of the scientific enterprise. Some of the topics are pressure and buoyancy, heat, motion, sound, mixtures, solutions, compounds, electricity, light, radioactivity, and rocks and minerals. Very simple apparatus and equipment are used in the performance of the experiments. Verbal and intuitive understanding of concepts and principles are emphasized. Quantitative mathematical description is minimized. Provided for each experiment are background information, laboratory procedures, and questions. (RS)

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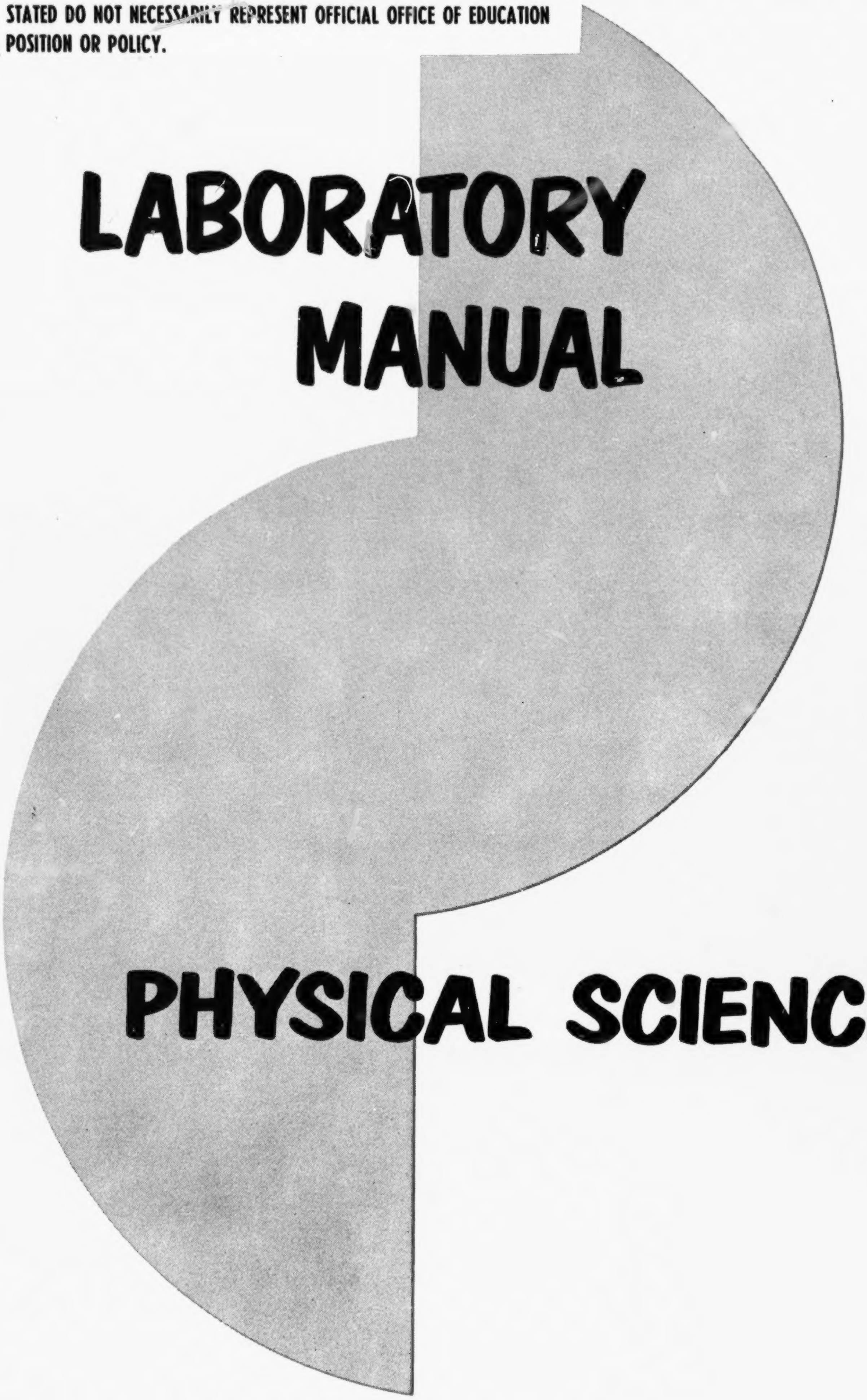
EXPERIMENTAL VERSION



# LABORATORY MANUAL

# PHYSICAL SCIENCE

SE 007 170

COOPERATIVE GENERAL SCIENCE PROJECT

C.G.S.P. Staff

# Physical Science

ATLANTA, GA.

CLARK
MOREHOUSE
MORRIS BROWN
and SPELMAN COLLEGES

## PREFACE

The teaching of physical science illustrates a very important philosophy of education; one which is too often overlooked. Learning is related to the ability to verbalize our thoughts. Many of the physical laws or principles taught in physical science are subconsciously recognized by us since we must adjust our lives to these basic principles; but we often find ourselves amazed at the consequences of these physical principles when we have these concepts verbalized for us or are forced to verbalize these principles to ourselves. It should be recognized that we do not really have the mastery of any knowledge until we have a conscious awareness of it which necessitates the ability to express our knowledge and concepts in words.

Preliminary studies indicated that many of the students who take a single physical science course in college have little previous training or background in science or mathematics. It is recognized that one of the basic reasons for the mental block many individuals have against physical science is the importance placed on mathematics in the teaching of physical science and to the poor mastery many individuals have of the materials of mathematics. Mathematical representation employs shorthand symbols to denote concepts that can be quantified, and these individuals have not come to associate these shorthand symbols with the concrete physical reality they describe.

It must be recognized that a mastery of mathematical materials is a necessity for those who want to effect a practical implementation of physical laws and principles in a technological world. However, many of us will devote our lives to other areas of activity and work. These individuals need to understand our scientific accomplishments, appreciate the potential of science, and realize the importance these matters have for the growth and development of our society. For this educated group of people, a verbal and intuitive understanding of the concepts and principles of physcial science is of more importance than a quantitative mathematical description.

The following group of experiments has been written and put together by the staff of the Cooperative General Science Project with the hope that the liberal arts majors who take this course will develop their ability to express and understand more fully the concepts and principles taught in a special course in Physical Science designed specifically for them. Realizing it would be impossible to present a comprehensive study in the sciences, it was decided to deal with only a small number of topics representative of the scientific enterprise. An effort has been made to relate the materials covered in the course to previous experience and to make the presentation of these materials of practical use to the students. It is hoped that our physical science course will develop the interest and curiosity of the students so they will explore their every day experiences and recognize underlying principles.

Since it is realized that the liberal arts major will not be following scientific careers in research and technology, we have attempted to utilize very simple apparatus and equipment to illustrate the principles. Learning is easier when the individual can associate the task at hand with previous experiences and it is more meaningful when he can project this knowledge into future useful situations. The laboratory experiments have been made an integral part of the course and complement the lectures by physically involving the students in experiences which illustrate the concepts and principles discussed in the classroom. Mathematical analysis of certain phenomena is utilized in the course as supportive evidence for the principles taught and as an opportunity for the students to become more competent in the area, but emphasis has been placed on graphical analysis and the functional representation of physical relations.

It is the sincere desire of the staff who developed this manual that its use by the students will be the beginning of a lifetime of enjoyment in observing and wondering and coming to know more about the world we live in.

## ACKNOWLEDGMENTS

This experimental version of Physical Science laboratory exercises represents the efforts of many individuals on the staff of the Cooperative General Science Project. While it is realized that some of the staff members contributed more to the development of this work than others, it becomes difficult to give special acknowledgement to a few individuals without slighting others. I wish to express my appreciation to each member of the staff for the interest they have exhibited in this work and the efforts they have expended in its development.

I would like to express special thanks to the United States Office of Education for the financial support of this project. It has contributed greatly to the improvement of our academic program and it is hoped that our efforts in producing this material will be of benefit to other educational institutions.

I am grateful, also, to the administrations of the four participating colleges, to Presidents Vivian Henderson, Hugh Gloster, John Middleton, and Albert Manley for their foresight in establishing this program. We owe special thanks to the various chairmen of the departments who encouraged this program and to deans of the various colleges for their cooperation.

July 30, 1968

Atlanta, Georgia
USA

O. P. PURI
DIRECTOR

# TABLE OF CONTENTS

Page

Preface ---------- iii

Acknowledgements ---------- v

Exercise

1 Methods of Graphical Analysis ---------- 1

2 Mathematical Relationships ---------- 8

3 Pressure and Buoyancy ---------- 14

4 Heat 1 - Gas Laws and Temperature Scales ---------- 19

5 Heat 2 - Conduction, Convection, and Radiation ---------- 24

6 Velocity and Constant Acceleration ---------- 28

7 Newton's Laws and Momentum ---------- 34

8 Vectors and the Resolution of Forces ---------- 38

9 Rotary Motion ---------- 43

10 Harmonic Motion and the Simple Pendulum ---------- 47

11 Sound ---------- 50

12 Elements, Mixtures, and Compounds ---------- 54

13 Solutions ---------- 58

14 Separation of Mixtures ---------- 63

15 Static Electricity ---------- 67

16 Electrical Circuits ---------------------------------- 71
17 Electrical Induction---------------------------------- 75
18 Light ---------------------------------------------- 79
19 Lenses -------------------------------------------- 86
20 Radioactivity---------------------------------------- 91
21 Rocks and Minerals----------------------------------- 94

Appendix ---------------------------------------------- 101

Conversion Tables ------------------------------------ 103

Personnel -------------------------------------------- 105

# EXPERIMENT
# 1

## METHODS OF GRAPHICAL ANALYSIS

Graphical analysis gives a picture or a visualization of how one quantity changes with respect to another. Graphs are used extensively by scientists as they search for relationships since graphs reveal some relationships clearly and they are one of the least involved methods of determining relationships. This laboratory exercise will give you some of the procedures which should be followed in constructing graphs and familiarize you with some of the simpler relationships shown by graphs.

In constructing a graph, observe the following rules:

1) Draw two straight lines intersecting at right angles with the horizontal line at the bottom of the graph and the vertical line at the left. These lines are known as coordinate axes.
2) In this course, we require the origin (or intersection of the axes) to always represent zero for both axes.
3) Choose convenient scales and allow equal spaces to represent equal changes on the scales.
4) A title should be at the top of each graph stating what things are being plotted against each other.
5) The quantity being plotted along each axis should be stated clearly on that axis.
6) Whenever the scale along either axis has units associated with it, the units should be stated clearly with the scale along that axis.

The simplest type of graph is the straight line graph. This type of graph is encountered when the two variables are directly proportional to each other.

To illustrate the straight line graph, suppose that when a pine tree was 4 years old, it was observed to be 2 feet high. Its height for a few years afterward was measured and recorded in the table below:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time (years) | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Height (feet) | 2 | $2\frac{1}{2}$ | 3 | $3\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 5 | $5\frac{1}{2}$ | 6 |

Suppose we wanted to know how high the tree had grown after 22 years (assuming it was still growing at the same rate.) By observing that its height increased by 1/2 foot for each year after we started measuring it, we could compute the height by saying the height = 2 feet + (1/2 ft/yr) x (18 years) = 2 feet + 9 feet = 11 feet. (The quantity, 18 years, was obtained by subtracting the age of 4 years when we started measuring from the age of 22 years when we wanted to know the height.)

Another way to determine the height of the tree would be to draw a graph of the height of the tree against the time that the tree was growing. This graph has been drawn in Figure 1 and turns out to be a straight line. Then by knowing any time that the tree has been growing, the corresponding height of the tree can be read directly from the graph.

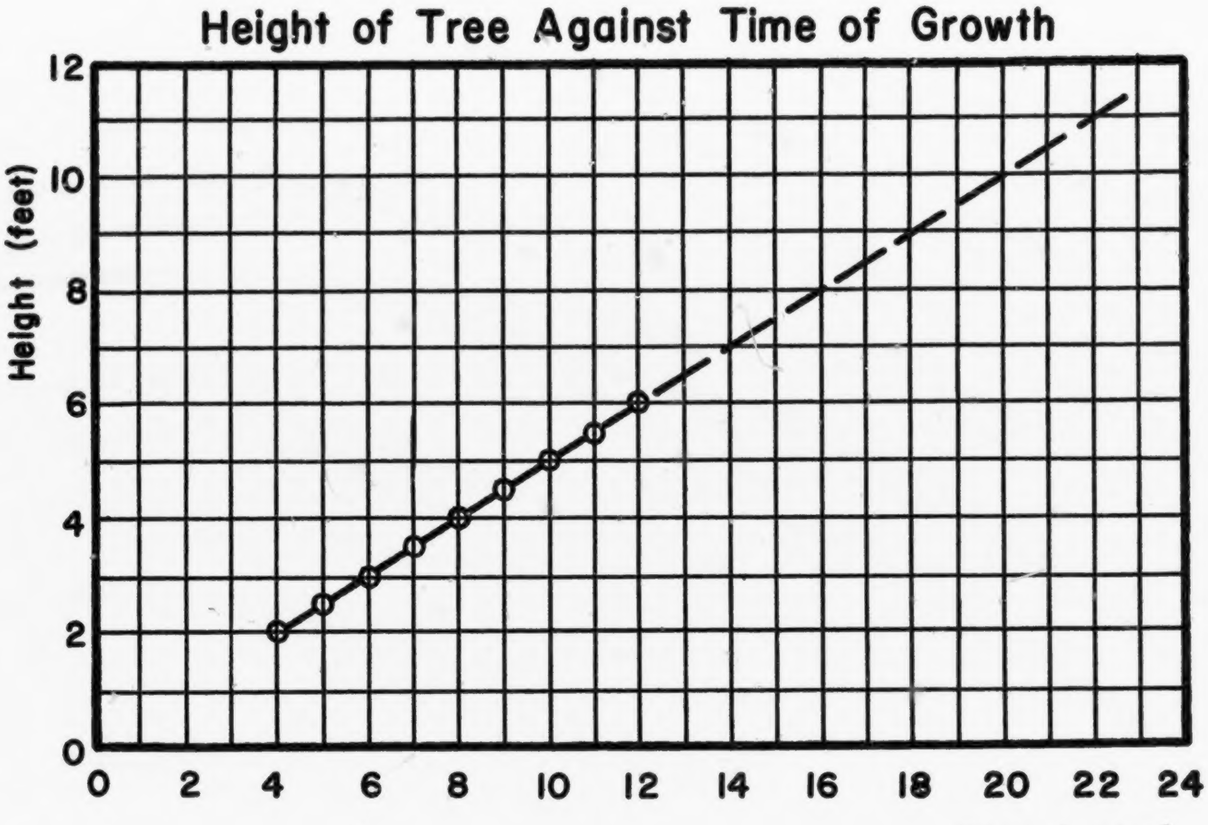


Figure l.

This straight line graph shows a relationship which can be expressed mathematically.

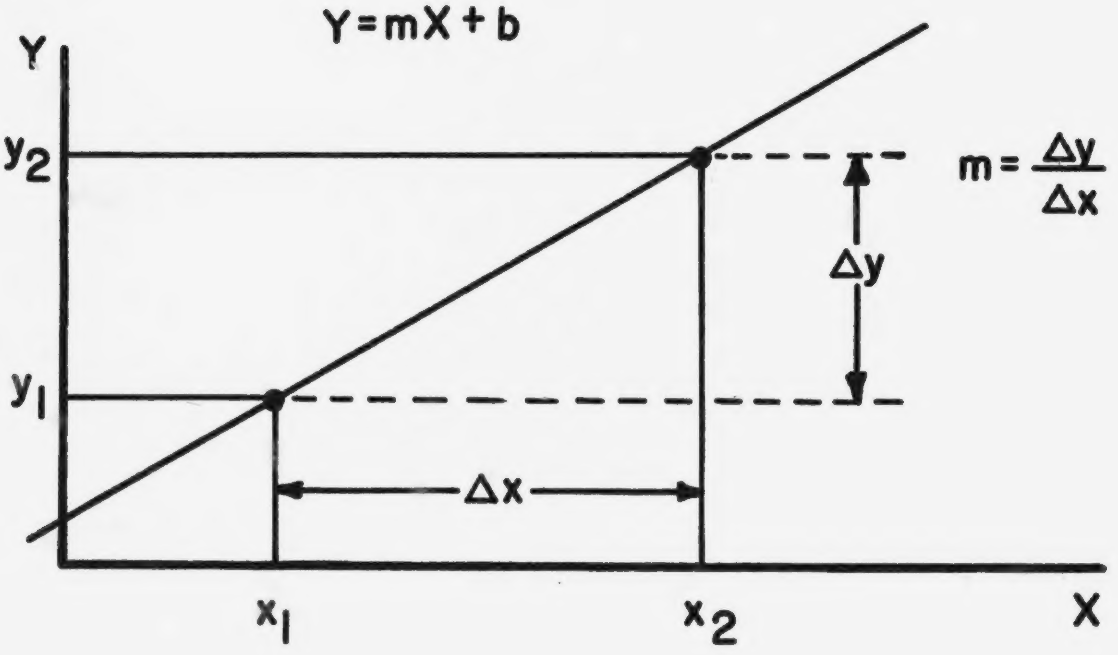


Figure 2.

The equation for any straight line, such as the one in Figure 2, is of the general form $y = mx + b$, where m is the slope of the line and b is the y-intercept of the line. (The y-intercept is the point at which the line crosses the y-axis - or vertical axis.) In general, these numbers are different for every straight line graph. When $x = 0$, $y = b$. Thus the proper value for b, the y-intercept of a line, can be found by setting $x = 0$ and reading off the values for y. This value may be positive, negative, or zero. The value of m, the slope of the line, is defined as the quotient of the change in the y-coordinate or vertical scale ( called $\Delta y$) and the change in the x-coordinate or horizontal scale ( called $\Delta x$). This slope can be positive, negative, or zero.

To find the slope of a line, choose any two points on the line, $(x_1, y_1)$ and $(x_2, y_2)$. Then, the

$$\text{slope} = \frac{\text{change in y-coordinate}}{\text{change in x-coordinate}} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$$

You have now seen the value, importance, and utility of the straight line graph. Note that when you have a straight line graph, the two variables are directly proportional - and, when the two variables are directly proportional, their graph is a straight line. That is, for every change in one of the variables, there is a corresponding change in the other variable. These changes are such that, if a given change in one variable, say x by an amount $\Delta x$, produces a change in the other variable, say y by an amount $\Delta y$, then the same change in y ( $\Delta y$) will be produced no matter where the change in x ( $\Delta x$) is taken on the x-axis. (Be certain you completely understand this important concept and ask your instructor questions if you do not entirely understand it.) This statement contains the most important features of what is meant by saying one quantity, y, is directly proportional to another quantity, x. If you plot a graph of one quantity against another quantity and the result is not a straight line, then the two quantities are not directly proportional.

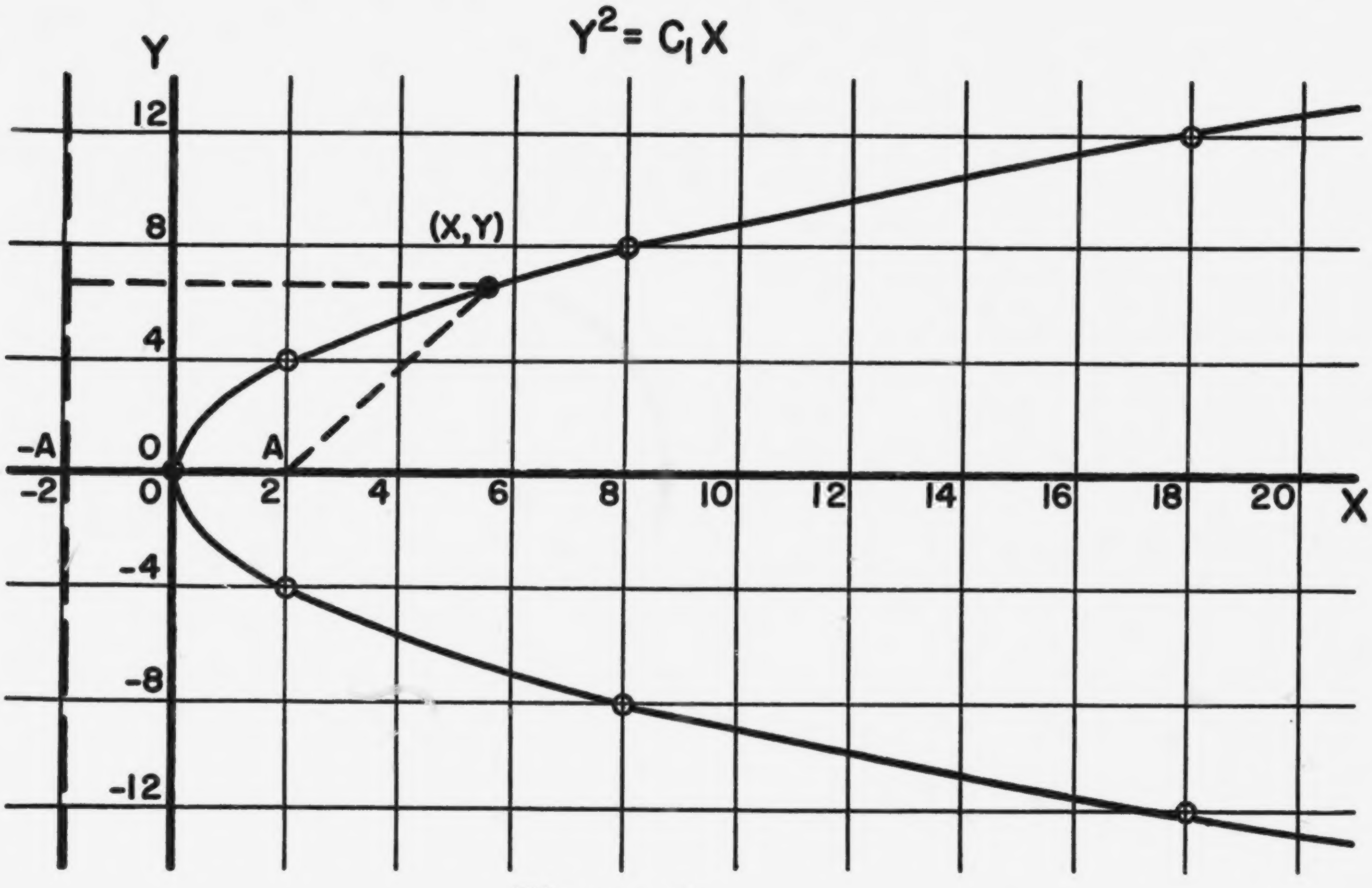


Figure 3.

Another common curve is the parabola. An example of a parabola is the curve illustrated in Figure 3. The equation of this line is of the form $y^2 = C_1x$, where $C_1$ is a positive constant. (In this case, $C_1 = 8$.) This curve was found to be drawn in such a way that every point $(X, Y)$ on the curve is the same distance from the point $(+A, 0)$, called the focus, as it is from the line $x = -A$, called the directrix. (The notation $(a, b)$ means the point represented on the graph is at $x = a$ and $y = b$.)

If we have a parabola, we would say that one of the variables is directly proportional to the square of the other or to the square root of the other. Thus, in the example in Figure 3, we could say that x is directly proportional to the square of y or that y is directly proportional to the square root of x. By squaring the values of y and replotting the new data on a graph whose vertical axis represents $y^2$ a straight line can be obtained. How else can a straight line be obtained from the same information?

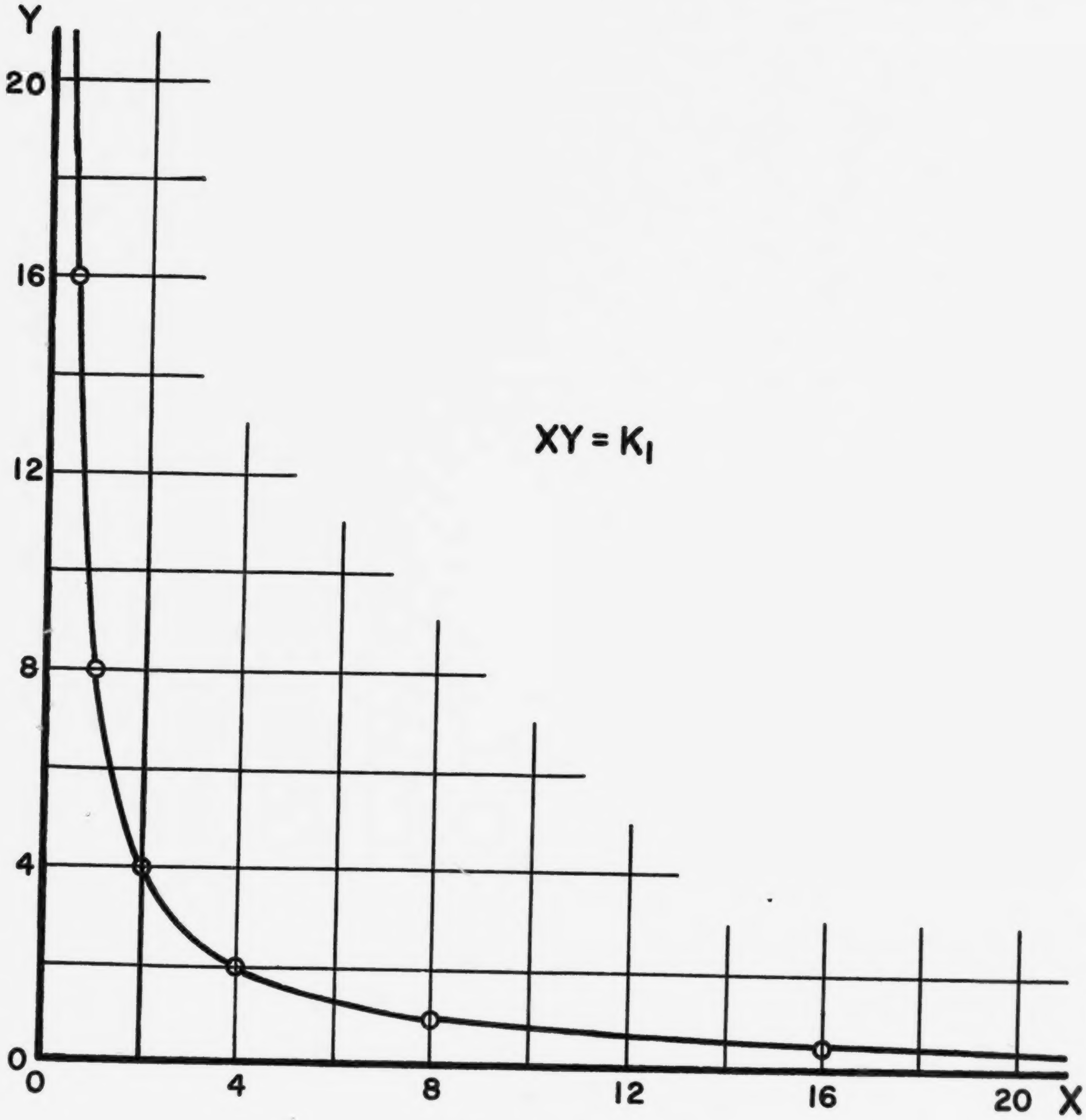


Figure 4.

The curve in Figure 4 is called a hyperbola. In this curve, the product of the coordinates is the same for all points on the curve, that is $xy = K_1$. (In this case, $xy = 8$.)

Notice that, as the x-coordinate gets larger, the y-coordinate gets smaller so that the product of the two can remain constant. In a hyperbola, we say that x and y are inversely proportional. How can a straight line graph be obtained in this situation?

## PROCEDURE

Plot points representing the length of a coil spring against the weight (in washers) hung from the spring on a graph. (Do not exceed ten washers.) Draw a curve connecting the points. What relationship between extension of spring and weight (or force) is shown by the graph? What would be the length of the spring if 5-1/2 washers were hung from it? How could you make this apparatus into a weighing scale? Develop a mathematical equation which will represent the curve shown on your graph using L for length and F for weight.

Plot each of the sets of data your instructor will give you on a suitable set of axes.

## NOTE

1) Sometimes, the points you will obtain will lie on neither a straight line nor one of the "smooth" curves which have been mentioned. In this case, one often draws a curve to approximate the values of the data.
2) Make each of your graphs as large as possible so you can see the relationship more easily.
3) If your graph of one quantity plotted directly against the other is not a straight line, compare the graph with the hyperbola and the parabola shown in Figures 3 and 4 and replot your graph using $y^2$ against x or $1/y$ against x, etc. so you can obtain a straight line graph. It is only when you have linear scales and a straight line graph that you can tell what the relationship between the variables is.

## QUESTIONS

1. Graphs are commonly used in analyzing the stock market. What do the coordinate axes usually represent in such graphs?

2. List three types of graphs, other than the type we have discussed in this experiment, commonly used in our society, and state how their forms differ from the type of graphs we have discussed in this experiment.

3. What relationships exist, if any, between the variables represented in the graphs named in the above questions?

EXPERIMENT
2

## MATHEMATICAL RELATIONSHIPS

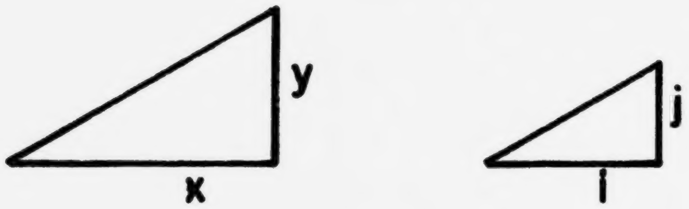
In the everyday world, as well as in the scientific world, the concepts of variation, variable, ratio, proportion, and function are used to describe certain features in an accurate and precise manner. Therefore, it is important to have a clear understanding of what is meant by these terms and how they are applied.

Variation refers to a change in a quantity called the variable. The outside temperature is an example of a variable. Let us call it T. If it is cool in the morning, warms up toward noon, and gets very warm in the afternoon, the temperature varies from one hour to another. The body temperature, on the other hand, remains about the same despite the outside temperature. We therefore call the body temperature a constant. Separate symbols - such as C or K - are often used to describe constants that are different from the symbols used to describe the variables in a given situation.

A proportion is a statement that two ratios are equal. It is of the form:

$$\frac{a}{b} = \frac{c}{d} .$$

For example, if we have two triangles whose corresponding angles are equal as follows:



we can say the side x divided by the side y equals the side i divided by the side j and write:

$$\frac{x}{y} = \frac{i}{j} .$$

This is a theorem in geometry which states that if two triangles are "similar", the corresponding sides are proportional. Rewrite this proportion in the form of an equation to solve for y.

When one quantity (the variable x) behaves in such a way that when a particular value is assigned to it another quantity (the variable y) is determined, we say that y is a function of x and we write

$$y = f(x).$$

THIS IS ALL THAT IS MEANT BY THESE SYMBOLS.

If one works for a given amount of money per hour, then the wages, W, will be determined by the number of hours, t, that one works, or

$$W = f(t).$$

If one worked for \$2.00 per hour, then we could find W by multiplying the number of hours worked, t, by \$2.00 to find the wages. The formula for finding the wages for a given number of hours would then be the function:

$$W = (\$2.00/\text{hr})\ (t \text{ hours}).$$

In this case, the quantity \$2.00/hr is a constant called the proportionality constant. It is the value of the fixed proportion or ratio between wages earned and hours worked in this example. It has units that convert the units of one of the variables into the units of the other variable. In this example, it converts the time in units of hours into wages in units of dollars.

Since we think of the time, t, as determining the wages, W, in the above function, we call t the independent variable because a person can change its value to whatever he wants to. W, the wages, is determined by how much t is, however. We therefore think of W as depending upon t and call W a dependent variable. Give another example and designate which variable would be called the dependent variable and which variable would be called the independent variable.

Another example of the concepts being discussed this week is something you will find helpful in the rest of this course and will aid you later on in life. Throughout most of the world and frequently in the many fields of science, a different system of measurement than the one to which you are accustomed is used. It is called the metric system and it uses different basic quantities and units to measure length and weight than the so-called English system that is common in the United States. Instead of the foot for measuring length, it uses the meter. Instead of the pound for measuring weight, it uses the gram and the newton. (Neither the English system nor the metric system is "best". They both are equally as accurate and correct. THE BASIC REASONS FOR CHOOSING ONE SYSTEM OVER ANOTHER ARE CONVENIENCE AND HABIT.)

To change from one set of units to another in a given system or to change from one system to another, we make use of the proportionality constants between the old and the new units. It is easiest to do this by setting up a function or formula in which the old unit is the independent variable and the new unit is the dependent variable.

Example: How many yards are there in X miles?

To do this problem, we use the following proportionality constants:

1 mile = 5280 feet
1 yard = 3 feet

then: $$Y \text{ yards} = (X \text{ miles}) \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{1 \text{ yard}}{3 \text{ feet}}$$

(Notice that, by setting up the function in this manner, you can cancel out the units and make sure that you have set up the function correctly, as indicated by the following illustration:)

$$Y \text{ yards} = (X \cancel{\text{ miles}}) \times \frac{5280 \cancel{\text{ feet}}}{\cancel{1 \text{ mile}}} \times \frac{1 \text{ yard}}{\cancel{3 \text{ feet}}} = (X) \times \frac{5280}{3} \text{ yards}$$

Some other proportionality constants are:

1 inch = 2.54 centimeters
1 meter = 100 centimeters
1 meter = 1000 millimeters

Measure the length of one of the laboratory tables in inches. By use of the given proportionality constants calculate its length in centimeters. Does this agree with actual measurement? Measure its height in centimeters. Calculate its height in yards by use of proportionality constants. Check your work with someone who measured a different table. If your figures are not the same, give some explanation for the differences. Is it possible that someone else could measure the same table you did and obtain slightly different answers? Explain.

A further example that will help your understanding of these concepts is the definite ratio that can be formed between the weight of a material and the volume of the material. The ratio is called the weight density of the material and it is defined as the weight per unit volume or

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

When a constant, representative of the particular material, is inserted as the density of the material, the above example becomes a proportion.

The reason a piece of iron is heavier than a piece of wood of the same size is that the densities of the two materials are different. We can measure the weight density in any units of weight and any units of volume, but it is generally the case that only certain units of weight are combined with certain units of volume.

## PROCEDURE

Measure and record the length, width, and height of each of the three metal blocks in both the English and metric systems. Calculate their volumes in both systems. Weigh each of the three blocks in the metric system and calculate their densities in units of grams per cubic centimeter ($gm/cm^3$ or gm/cc). Compare your results with the results of other students who measured similar blocks. What accounts for the differences? How would you suggest agreement be reached by the whole class for the densities of these blocks? Does the density of the slab match the density of one of the cubes? Does this prove the slab and one of the cubes are made of the same material? Explain.

Compute the density of water in gm/cc by weighing 20 cc of water measured from a pipette or burette. (Use a clean, dry beaker.) Why is it slightly less than 1 gm/cc? Why is it suggested you use a pipette or burette rather than a graduated cylinder?

Determine the density of anti-freeze by weighing 20 cc of anti-freeze measured from a pipette or burette. (Be sure the beaker is dry before using.) Why should you weigh the empty beaker, again, since you have already weighed it in the previous calculation? After use, why should you not pour the anti-freeze back into its original container?

From a pipette or burette measure out 5 cc of water into a clean, dry beaker and, by use of a medicine dropper, determine the volume of one drop of water. Using the density of water determine how much one drop of water should weigh.

## NOTE

It is frequently convenient to set up a proportion comparing the density of one material with the density of water. This proportion will be a constant for the material and is called specific gravity of the material. The proportion is set up in the following manner:

$$\text{Specific Gravity of A} = \frac{\text{Density of A}}{\text{Density of water}},$$

where the density of A and the density of water are both measured in the same units. Will specific gravity have any units? What is the specific gravity of anti-freeze?

## QUESTIONS

1. What is the speed of a car in ft/sec when it is traveling at 60 mi/hr? (Use proportionality constants and show unit cancellations.)

2. How many millimeters are in 7 feet?

3. What is the piston displacement in cubic centimeters of a car which has a piston displacement of 11 cubic inches.

4. Suppose you are traveling in Europe by car and you want to buy 50 liters of gasoline (Petrol). How many gallons of gasoline is this? (1 liter = 1.06 quarts.)

## EXPERIMENT
## 3

## PRESSURE AND BUOYANCY

The concepts of force and pressure are frequently confused by large numbers of people. In this experiment, we will investigate the similarities and differences between these two concepts. Also, we will look at a closely related topic, that of buoyancy - or the reason that some things can float on the surface of a liquid or rise in gas.

The pressure being exerted upon the surface of an object is defined as the force per unit of area. The primary reason for the confusion that exists between the concepts of force and pressure is that, in most circumstances, both a pressure and a force are encountered. For example, when you are sitting in a chair, you can feel the chair pushing up on you with a total force that is just equal to that of the earth's force of gravity on you. This is the total amount of the force that you can feel. However, each part of your body that feels this force is actually feeling the pressure that is being exerted upon that part of your body. If the chair has a large, well-padded cushion, the overall force is distributed over a larger area and the resulting pressure is reduced at any particular smaller area of your body. Since the pressure is small, you can probably sit comfortably for a long period of time. If, however, you are sitting on a narrow rail on the top of a fence, the total force is the same as it was when you were sitting on the chair, but now the area has been considerably reduced so that any portion of your body that is in contact with the top of the rail experiences a much larger pressure than you encountered in the chair.

The result is that you are much more uncomfortable sitting on the top of a fence than in a well-padded chair because of the difference in pressure that is being exerted on your body in the two cases even though the force involved is identical in each case. In most of the cases in which you can feel a force being exerted, the force is exerted over some area so that it may become difficult, without careful thought, to decide whether it is the force or the pressure that you are reacting to.

Pressures resulting from forces behave differently when they are applied to gases or liquids (which we may group together as fluids) than when they are applied to solids. When a force is applied to the surface of a solid, the resulting pressure is transmitted through the solid only in the direction of the force. Since liquids and gases have no fixed form (the molecules making up the fluid are free to move in any direction), the pressure at any particular point is uniform in all directions.

The pressure we are most familiar with in our atmosphere and underwater is caused by the weight of the air and water above us. For example, atmospheric pressure is 14.7 $lb/in^2$ at sea level which indicates the column of air above each area of one square inch weighs 14.7 lbs. Water weighs approximately 64 $lb/ft^3$. This means that for every foot we go below the surface of the water we will have 64 more pounds pressing against each area of one square foot. At a depth of 10 ft of water, the pressure builds up to 640 $lb/ft^2$ of surface area in addition to whatever atmospheric pressure is exerted on the surface of the water. A swimmer who dives below the surface of the water does not feel the weight of the water above him pressing him down because the pressure of the water against his body is the same from all directions at the same depth.

In unenclosed fluids such as bodies of water and our atmosphere, when an object is lowered into the fluid a volume of fluid equal to the volume of the object that is beneath the surface of the fluid will be displaced and the level of the fluid will rise. Since the fluid itself has weight, this means that the pressure in the fluid will increase. The result of this increase in the pressure is that a force equal to the weight of the fluid that has been displaced will be applied to the bottom of the object such that the fluid will try to return to its former position by moving the object out of the fluid. This force is called the buoyant force. The phenomenon itself, called buoyancy, was first discovered by Archimedes in ancient Greece.

If the weight density of the object that is placed in the fluid is smaller than the weight density of the fluid, it will sink in the fluid until it has displaced a volume of the fluid that has the same weight as the object. That is, a block of wood when placed in water will sink into the water until it has displaced a volume of water equal to its own weight. At this point the force due to the weight of the wood is just equal to the buoyant force of the water, and the wood floats.

If the weight density of the object is greater than the weight density of the fluid, the object will submerge completely in the fluid. As you go deeper into the fluid, the pressure increases due to the weight of the fluid that is above you. When an object is completely submerged in a fluid, there will be a difference in pressure between the upper and lower surfaces of the object that is equal to the weight of the fluid displaced divided by the area of the top or bottom of the object. This results in a buoyant force acting on the bottom of the object that is equal to the weight of the fluid displaced.

Most of us can regulate whether we float or sink in water by either inhaling a lot of air and holding our breath or by exhaling much of the air out of our lungs. An expanded chest would give our bodies more volume without noticeably increasing our weight, thus increasing the upward force exerted due to the displaced water. As we breathe out we reduce our volume and, consequently, reduce the upward buoyant force due to the displaced water. Salt water is more dense than fresh water and the buoyant force of salt water is greater than fresh water. The density of Great Salt Lake in Utah is so high due to its high salt content that many people find it difficult to surface dive and get their bodies below the surface of the water. Most objects we are familiar with, including iron, will float in mercury, a very dense liquid.

When a force is applied to an enclosed fluid, the resulting increase in pressure is present throughout the fluid. An example of this would be found if we placed a balloon on a table and then placed a weight on the balloon. The resulting pressure is still transmitted to the surface of the table beneath the balloon, but it is also transmitted to the sides of the balloon. If you had placed your hands on the sides of the balloon before the weight was put on top, you would have been able to feel the increase in pressure on your hands being transmitted through the sides of the balloon.

The ability of an enclosed fluid to have the same pressure on all of its surface due to the application of a force in any one particular areas has many applications that you see every day. One example is found in the hydraulic lift at a gas station. A small force of perhaps 50 pounds is applied to a small area of perhaps 2 square inches on the surface of a volume of oil. This raises the pressure throughout the oil by 50/2 or 25 $lb/in^2$. The lift itself consists of two metal tubes that are closed off so that the pressure is exerted on their ends, both of which are about 100 square inches in area. The force on the bottom of the lift due to the 25 $lb/in^2$ pressure is therefore equal to the pressure multiplied by the area or

$$\text{Force} = (25 \text{ lb/in}^2) \times (200 \text{ in}^2) = 5,000 \text{ pounds}$$

which may be used to raise an automobile easily.

## PROCEDURE

Weigh an iron rod in air by hanging it by thread or string with the bottom of the iron rod approximately 3/4 inch above the platform on one of the balances. Place a graduated cylinder containing 25 ml of water on the platform and weigh the iron rod while it completely immersed in the water. (BE SURE THE IRON ROD IS NOT RESTING ON THE BOTTOM OF THE CYLINDER.) Record the volume of water displaced and calculate how much that volume of water would weigh. How much did the iron rod lose in weight when immersed in water? Do these figures agree? Why? Calculate the density of the iron rod.

When an object sinks in water you can determine the specific gravity of it by dividing the object's weight in air by the loss of weight when immersed in water. Determine the specific gravity of the iron in this manner and explain why this is true. (HINT: specific gravity = $\frac{\text{density of object}}{\text{density of water}}$) How does the density of the iron compare with its specific gravity?

Weigh a wooden dowel rod. Place the wooden dowel rod in a graduated cylinder containing 25 ml.of water. Record the volume of water it displaces while it floats and calculate how much that volume of water would weigh. Do these figures agree? How can you easily determine the volume of the wooden dowel rod? What is the density of the wooden dowel rod?

When an object floats in water you can determine the specific gravity of it by dividing the volume of water it displaces by the volume of the object. Determine the specific gravity of the wooden dowel rod in this manner and explain why this is true. ( SAME HINT AS ABOVE.)

A "Cartesian diver" is located at the front of the room. Observe the action of the Cartesian diver when the diaphragm is depressed and explain what happens when the diaphragm is depressed to cause the Cartesian diver to sink.

Lift pumps and force pumps are located near the water outlets. Operate them and study them until their principles are understood. What causes a lift pump to function? What advantages does a lift pump have over a force pump? What advantages does a force pump have over a lift pump?

A hydraulic lift is located at the front of the room. Work in groups by lifting each other with the hydraulic lift. What causes the hydraulic lift to multiply effort?

QUESTIONS

1. If atmospheric pressure is 14.7 $lb/in^2$, what is the atmospheric pressure in units of $lb/ft^2$ ?

2. A 100 lb woman wearing high heel shoes stands still placing half her weight on her heels. Each heel measures 1/2" x 1/2". How much pressure is being exerted on the floor by her heels?

3. A 4000 lb elephant in a zoo is standing still with its weight equally supported by four legs. Each foot has an area of 1 square foot pressing against the floor. How much pressure is being exerted on the floor in units of $lb/in^2$ by the elephant?

4. In Asia, people test eggs the following way: If the egg sinks - it is fresh, and if it floats - it is stale. Explain.

EXPERIMENT
4

## HEAT I - GAS LAWS AND TEMPERATURE SCALES

Heat and temperature are related, but there is a definite difference in our concepts of them. Heat is a measurement of the total energy involved while temperature is a measurement of the average energy of a substance. We measure heat in calories in the metric system and British Thermal Units (BTU's) in the English system, while we measure temperature in degrees Centigrade (or Celsius) and in degrees Kelvin in the metric system.

All matter is composed of entities called atoms. Often, two or more atoms are combined to form molecules although some atoms may be considered to be individual molecules. Molecules are the building blocks of all matter. When a material absorbs heat (or energy) the molecules move faster and collide with each other more often and more vigorously. Under these conditions, each molecule tends to take up more space and the material expands in all directions. We use this characteristic of molecules to develop such things as the thermometer. As the molecules in the liquid comprising a thermometer absorb energy the volume of the liquid becomes greater and the liquid rises in the glass tube of the thermometer.

The scale reading on the thermometer has been arbitrarily chosen and would indicate the average energy of the molecules. By determining the amount of the substance involved and multiplying that factor by the average energy (temperature) of the molecules we can calculate the total amount of energy involved (heat).

Since the heat of a substance is directly proportional to the temperature of the substance it is sufficient in studying the characteristics of different materials when subjected to energy or heat to relate these changes to their temperatures.

The three common states of matter are: solid - a fixed number of molecules having a fixed volume and a fixed shape; liquid - a fixed number of molecules having a fixed volume but no fixed shape; and gas - a fixed number of molecules having no fixed volume and no fixed shape. These different states occur as the energy of the molecules increases and each molecule moves more freely. The bonds or forces which hold the molecules together get weaker until, as a gas, each molecule bounces around in space completely disassociated with any other molecules. Each material has its own particular temperatures for changing from one state to another and we sometimes refer to these temperatures as the melting (or freezing) point and the boiling (or condensing) point of the substance.

The common thermometers we use, calibrated in degrees Fahrenheit and Centigrade (or Celsius), have been arbitrarily scaled so that zero fits within the range of temperatures our senses are familiar with. It must be realized these readings would indicate the substances being studied still have quite a bit of energy. Absolute zero is approximately - 273°C which we have defined as 0°K. With this exception the Kelvin scale and the Centigrade scale are similarly scaled or graduated. 0°C would be 273°K and 100°C would be 373°K.

Figure 1 shows the relationships between the temperature scales. There are 180 degrees of change on the Fahrenheit scale between the freezing point of water and the boiling point of water while there are only 100 degrees of change on the Centigrade and Kelvin scales. Reducing this relationship we find that for every 9° change in Fahrenheit there is a corresponding 5° change in Centigrade or Kelvin. As long as we know the readings on both scales at one temperature point we can easily convert from one scale to the other. What is the temperature in degrees Centigrade when it is 203°F ?

Substances in solid or liquid form have been found to expand at different rates. We use this principle in developing a thermostat. The moving part of a thermostat is composed of two materials which expand at different rates and which have been welded together into a long strip. When the strip is heated it will bend as one side gets longer than the other thereby causing an electrical circuit to be broken or completed depending upon whether we are using the thermostat to control heating or cooling.

Gases have certain unique characteristics when compared with solids and liquids. It has been discovered that all gases have the same number of molecules in equal volumes when subjected to the same temperature and pressure. There are two primary laws involved named after the men who first discovered them. Boyle's Law states that the pressure of a given amount of gas is inversely proportional to the volume of the gas (when the temperature is constant), or

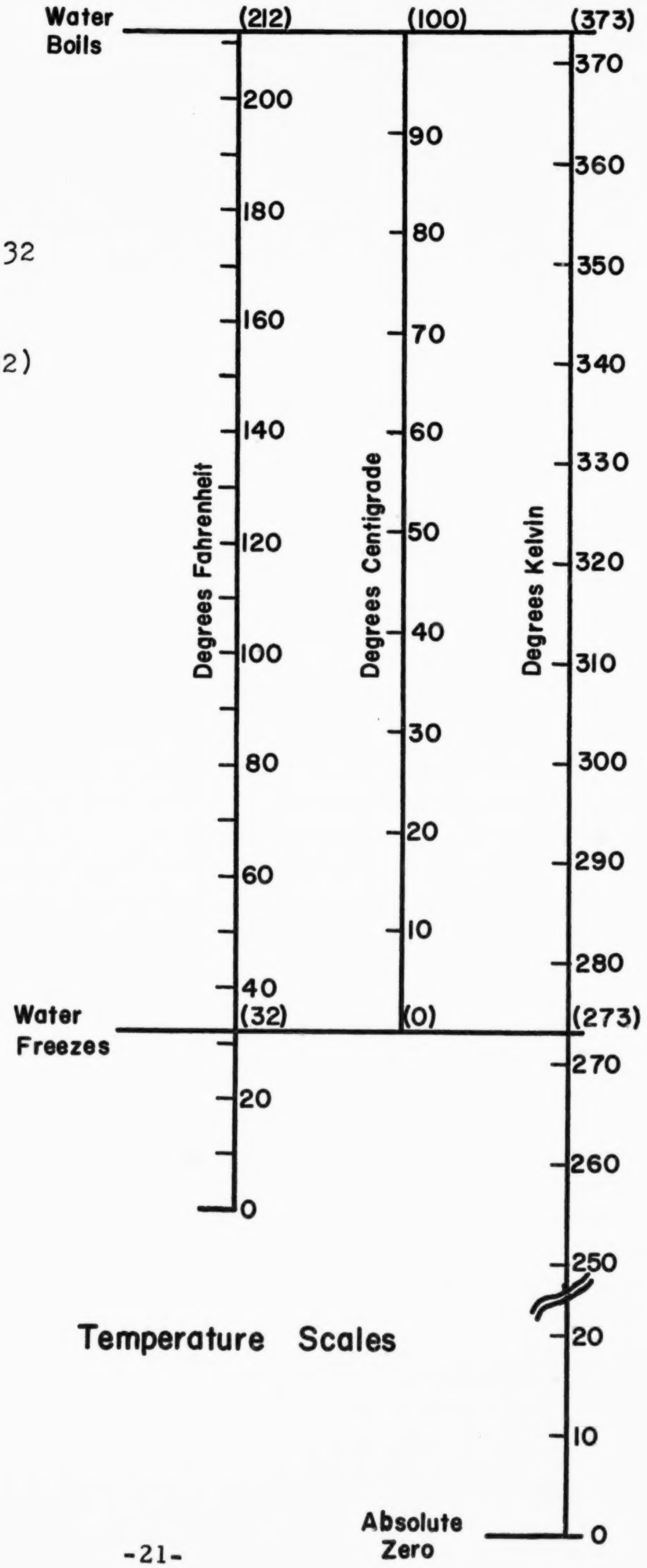
$$PV = K_1$$

where P is the pressure, V is the volume, and $K_1$ is a constant. Charles' Law states that the temperature of a given amount of a gas is directly proportional to the volume of the gas (when the pressure is constant), or

$$^{\circ}F = \frac{9}{5}(X)^{\circ}C + 32$$

$$^{\circ}C = \frac{5}{9}(X^{\circ}F - 32)$$

Figure I.


Water Boils
(212)
(100)
(373)
370
200
90
360
180
80
350
160
70
340
140
60
330
Degrees Fahrenheit
Degrees Centigrade
Degrees Kelvin
120
50
320
100
40
310
30
80
300
20
60
290
10
280
40
Water Freezes
(32)
(0)
(273)
270
20
260
0
250
20
10
Absolute Zero
0

Temperature Scales

$$V = K_2T$$

where T is the temperature measured in degrees in Kelvin and $K_2$ is a constant.

These two laws may be applied separately or together in any situation involving a gas. The combined form of these laws may be written as

$$PV = KT$$

where the constant, K, in this case depends only upon the number of molecules present.

## PROCEDURE

Observe the different conditions when the ball will go through the ring and the conditions when the ball cannot go through the ring when subjected to heat and cool water. Give a procedure whereby you can insert the ball through the ring but cannot pull the ball back through the ring.

The bimetal strip is made up of two metals; one metal is copper colored and the other is silvery. Heat the strip in a flame. Which metal expands more when heated? Cool the strip by running water over it. Which metal contracts more when cooled? Which side of the bimetal strip would you use as an electrical contact to control electrical current in an air conditioner?

Measure and record the temperature of cold tap water, hot tap water and boiling water in both the Fahrenheit and Centigrade temperature scales. Why is the boiling point of water less than $212^{o}$F and $100^{o}$C ?

Determine the boiling point of methanol (wood alcohol) in degrees Centigrade by placing 2 ml of the liquid in a pyrex test tube which has a thermometer in a two-hole rubber stopper suspended in it so that the bulb of the thermometer is about 1 inch above the surface of the liquid. Place the test tube in a beaker of water and heat the water to boiling until the condensation ring of the boiling methanol in the test tube covers the thermometer bulb and rises at least 1 cm above the thermometer bulb. When the thermometer reading in constant, record the boiling temperature. DO NOT HEAT THE TEST TUBE DIRECTLY IN THE FLAME OF THE BURNER. After the determination of the boiling point, wash and dry the test tube and the thermometer. Calculate the boiling point of methanol in degrees Fahrenheit.

Determine the melting point of napthalene (moth balls) by filling a test tube half-way with crystals. Melt the napthalene by placing the tube in the flame of the burner. (NOTE: If you have a test tube with napthalene crystals already solidified in the bottom, melt these with the burner and continue with the instructions.) Cool the liquid by placing the tube in a beaker of cool water. Shake the tube continuously and, when half of the liquid is solidified, measure the temperature by inserting the thermometer into the test tube. Remove the thermometer and repeat to get another reading. DO NOT HEAT THE TEST TUBE WHILE THE THERMOMETER IS IN IT AS YOU MAY OVERHEAT THE THERMOMETER AND BREAK IT. Clean the thermometer carefully. Place the test tube containing the napthalene in the rack for the next group of students.

Fill the plastic syringe with 35 cc of air and record the volume of gas as you apply various pressures by loading uniform weights on the wooden block. Eject the air and fill the plastic syringe with 35 cc of natural gas from the gas jets. Record the volume as you apply the same pressures as before. Plot these points representing volume versus pressure on the same graph using a small circle to represent air and a small square to represent natural gas. Draw a curve to connect these points. What type of relationship between volume and pressure is suggested by the graph? What other pressure is not taken into consideration in this experiment?

## QUESTIONS

1. What is our body temperature (98.6°F) in °C? in °K?

2. Why is colored alcohol used as the liquid in a weather thermometer rather than mercury?

3. Why is mercury used as the liquid in a cooking thermometer rather than colored alcohol?

4. A gear is mounted on a hollow pipe so that the gear will not slide on the pipe as the fit is "too tight". How would you separate the pipe and the gear with a blow torch? a sack of dry ice?

EXPERIMENT
5

## HEAT II - CONDUCTION, CONVECTION, AND RADIATION

Heat energy may be transferred from one place to another by three basic methods. Since heat energy is a result of motion by the atoms and molecules in a material, two of these methods are fairly obvious ways of transferring this motion from one place to another. The first method is conduction in which the molecules with a large amount of energy and motion bump into their neighbors that do not have as much energy so that the energetic molecules are slowed down and the less energetic molecules gain energy in much the same way that energy is passed from one ball to another on a pool table. Conduction takes place more rapidly in solid materials in which the molecules are held fairly rigidly in place and are not allowed to move about in the material.

The second method is convection whereby the more energetic molecules in one part of the material are physically moved to another part of the material so that the more energetic molecules are eventually spread equally throughout the material. These molecules will then lose some of their energy to the surrounding molecules by means of conduction-type collisions so that all of the molecules in the material end up with nearly the same amount of energy. Convection only occurs in fluids (liquids and gases). We speak of convection currents if convection occurs naturally, but man can artificially cause convection to occur by use of fans, pumps, and stirring rods. Convection currents are caused by the energetic molecules expanding and becoming less dense. These less dense molecules tend to rise in the liquid or gas as cooler, more dense molecules replace them and force the less dense molecules upward.

Finally, there is radiation. Unlike conduction and convection, where transfer of heat energy is dependent upon the motion and movement of molecules, heat transfer by radiation can take place through empty space or a vacuum. The sun is our primary source of energy and we receive this energy in the form of radiation. Often, a material will glow red or white if sufficiently heated, but it must be realized radiation can and does take place without the radiation being visible. A good example of this is the heat we feel radiating from a hot iron as infrared radiation from the iron is absorbed by the molecules in our skin. On a cold winter day a fire feels warm to one side of our bodies while the rest of our skin may still feel cold, demonstrating that the energy is being received by you without the temperature of the surrounding air being perceptibly increased as it would be in the case of either conduction or convection.

Quite frequently, all three methods of heat transference are taking place at the same time. In a steam heating system the steam is circulating through the system due to convection currents sometimes aided by pumps. As the molecules in the radiator absorb energy from the steam molecules by conduction it passes this energy along to air molecules which come in contact with it by conduction. These more energetic air molecules set up convection currents in a room to distribute themselves uniformly throughout the room. Without the use of fans to cause better circulation of the air molecules the more energetic molecules are forced to the top of a closed room. At the same time all of this is occurring the steam radiator is also emitting energy in the form of radiation.

Air is relatively a poor conductor of heat. If we can reduce the convection currents in air, air becomes a fairly good insulator. Animals which live in cold climates usually have a bushy fur composed of many fine hairs closely spaced. By trapping air molecules and not allowing a free flow of circulating air the air molecules close to the skin soon gain approximately the same energy as the skin molecules. This energy is gradually conducted outward and lost, but there is much less energy loss in this manner than there would be if the molecules of air close to the skin were replaced by the colder molecules of the surrounding air.

Since every substance has different atoms and molecules in its composition than any other substance, one would expect it ot react differently in respect to the amount of heat that has to be added to increase the motion of its atoms and molecules to cause a rise in temperature. This is indeed the case. The amount of heat energy that has to be added to or taken away from the material to cause a specific change in the temperature of the material is called the specific heat of the material. In the metric system, the unit of heat energy is called the calorie. A calorie is defined as the amount of energy required to change the temperature of one gram of water one degree Centigrade. (The Calorie used in measuring the energy obtained from foods is actually one thousand calories by this definition.) In the English system, the basic unit is the British Thermal Unit or BTU. (BTU's are frequently used to describe the size of heaters and air conditioners.) One BTU is defined as the amount of heat required to change the temperature of one pound of water one degree Fahrenheit. The specific heat of water is by definition one calorie per gram-degree Centigrade (1 cal/gm-$^{o}$C) in the metric system and 1 BTU/lb-$^{o}$F in the English system.

## PROCEDURE

Carefully weigh the small metal cup of the calorimeter and the stirring rod when they are clean and dry. Fill the cup half full of cold water from the tap. Weigh the cup and determine the amount of water in the cup. Weigh one of the pieces of metal at the front of the room when it is dry and place it in the beaker of boiling water at the front of the room and let it heat for 10 minutes. Record the temperature of the boiling water and also the cold water in the cup. Remove the piece of metal with the tongs and dry it carefully. Place the piece of metal in the cold water in the calorimeter. Move the stirring rod slowly and continuously in the water so the heat is evenly distributed throughout the cup. When the temperature of the water stops changing, record the temperature of the water. The increase in temperature of the water multiplied by the specific heat of water plus the increase in temperature of the metal cup and stirrer multiplied by the specific heat of the metal cup and stirrer should then equal the decrease in temperature of the piece of metal multiplied by the specific heat of the metal. You can determine the specific heats of the cup, stirrer, and the piece of metal from the handbook at the front of the room. Give reasons for any differences.

Using three beakers fill one beaker with ice water, one beaker with hot water (not scalding), and the third beaker with room temperature water (tepid). Place the index finger of one hand into the beaker of ice water and the index finger of the other hand into the beaker of hot water and hold them there for about two minutes. Then insert both fingers, side by side, into the beaker of tepid water. Explain why this water now feels cool to one finger and warm to the other finger.

Draw a diagram of a vacuum bottle, label the important features of it, and explain how it prevents heat transfer by conduction, by convection, and by radiation.

There are several different kinds of rods at each of the tables. Hold them together in a beaker of boiling water. As soon as one becomes too hot to hold put it down and continue to heat the rest. Continue until all of the rods become too hot to hold. Record the order of ability to conduct heat rapidly. What relation would this rapidity of conduction have to the specific heat of a substance?

Place some of the particles provided by your instructor in a beaker of water and heat it until it boils. Describe the convection currents illustrated by the movement of the particles.

There is a regular thermometer and one that has had its bulb blackened at each table. Placing the thermometers at equal distances from a heat lamp record change in temperature of each thermometer after a short time. What conclusion is suggested by this experiment?

Place both of the above mentioned thermometers in boiling water. When both of the thermometers have reached the temperature of the boiling water remove them and observe which one cools off more rapidly. What conclusion is suggested by this experiment?

QUESTIONS

1. Is coldness conducted from one object to another? Explain.

2. What causes dew to form during the night? (Explain by conduction, convection, and radiation.)

3. Why are clouds more prevalent over islands than over the surrounding water?

EXPERIMENT
6

## VELOCITY AND CONSTANT ACCELERATION

In this experiment, we will be studying the motion of falling bodies by using methods and reasoning similar to that used first by Galileo around 1600 A.D., when he did his classic work on falling bodies. When Galileo did this work, only very crude instruments were available for measuring time; he used his pulse and a water clock.

Galileo employed a slanted track and smooth balls for his experiment. We call this apparatus an inclined plane. It is not obvious that if one allows balls to roll down an inclined plane and arrives at conclusions about how they roll down the plane, that these conclusions will also be valid for freely falling bodies (or any other situation involving a constant acceleration). However, Galileo did convince himself that what he could arrive at in the way of conclusions about balls rolling down a plane also held for freely falling bodies near the earth's surface. He found that a ball rolled down a given plane (with a gentle slope) in such a way that the distance traversed was proportional to the time squared, or

$$s \propto t^2 .$$

On gradually increasing the slope of the plane, Galileo found that the distance was still proportional to the time squared. In short, Galileo observed that as the slope of the plane became greater and greater - approaching a vertical position - he always found that the distance the ball rolled down the plane was proportional to the time squared.

The total distance an object travels divided by the time required for traveling the distance is called the average velocity of that object. We write this as

$$v = \frac{s}{t}$$

where s is the distance, t the time, and v the ratio of these two quantities. Some units associated with velocity therefore would be miles per hour, feet per second, meters per second, and centimeters per second written as mi/hr, ft/sec, m/sec, and cm/sec.

If there is any change in the velocity of an object in a given time, we call this the acceleration and write

$$a = \frac{\Delta v}{t} \quad .$$

Some units associated with acceleration therefore would be miles per hour per hour, feet per second per second, meters per second per second, and centimeters per second per second written as mi/hr$^2$, ft/sec$^2$, m/sec$^2$, and cm/sec$^2$.

In each case, v or a, the quantities s or v and t must be changing, and it is the changes that are important. (For example, if you are going 50 mph in a car and look down and see that it is 10 o'clock, you do not divide 50 by 10 and get and acceleration of 5.)

Notice that, in the first relation, the definition gives only the average velocity of the object. (For example, if you were to take a trip in a car and traveled 300 miles in 6 hours, this relation would give your velocity as 300/6 or 50 miles per hour even though you may have been going as fast as 70 miles per hour or had to stop along the way to buy gasoline.) Similarly, the second relation would give only the average acceleration.

We will be able to study the difference between the average velocity of the object and the final velocity of the object in this experiment. The acceleration will be constant so that the value of the acceleration will be the same at any two positions along the inclined track and will be the same as the value of the average acceleration.

We can write Galileo's discovery down in symbols - something he did not do - and say

$$s \propto t^2$$

From the meaning of one thing being proportional to another - from $s \propto t^2$ - we can write

$$s = Kt^2$$

where K is a proportionality constant.

By using definitions of velocity and acceleration and a little careful thought, we can determine the value of the proportionality constant, K. If an object is acted upon by a constant acceleration and starts from rest, the change in the velocity, $\Delta v$, will just be the velocity at the end of a period of time, t, and we can write

$$\Delta v = at \; .$$

In this case $\Delta v$ will also be the final velocity. Before we can continue, we have to realize that all during the period of time, t, the velocity was constantly changing so that in order to determine how far the object has traveled, we will need to know the average velocity during the time, t. In this case, the average velocity is merely one-half of the final velocity. (This is true only if the acceleration is constant and the object starts from rest.) We can then write

$$\bar{v} = 1/2\, v_f = 1/2at.$$

(Often in science, the average value of a quantity is written as the symbol of the quantity with a line drawn over the symbol.) Substituting this value of the velocity into our first definition, we find

$$1/2at = \frac{s}{t} \text{ which we can write as } s = 1/2at^2 \; .$$

Now we can compare this with Galileo's result and see that

$$K = 1/2a \; .$$

This result is true whenever the acceleration is constant and the object starts from rest.

Thus, the acceleration being a constant is equivalent to Galileo's discovery. That is, if we know the distance is proportional to the time squared, we can conclude that the acceleration is constant - or, if we know that the acceleration is constant, we can conclude that the distance is proportional to the time squared.

The apparatus we will use consists of two slotted tracks. One is pitched at an angle so that a ball rolling down it will have a constant acceleration. THE DISTANCE THE BALL MOVES DOWN THE INCLINED TRACK DIVIDED BY THE TIME THAT THE BALL TAKES TO MOVE DOWN THE INCLINED TRACK WILL THEREFORE BE THE AVERAGE VELOCITY. The first track is attached to a second which is horizontal so that the acceleration is zero along it (the velocity of the ball will not change when the ball moves along the horizontal track). THE DISTANCE THE BALL MOVES ALONG THE HORIZONTAL TRACK DIVIDED BY THE TIME THE BALL TAKES TO MOVE ALONG THE HORIZONTAL TRACK WILL THEREFORE BE THE SAME AS THE FINAL VELOCITY THE BALL HAD AT THE BOTTOM OF THE INCLINED TRACK. A steel ball, a meter stick, and a clock complete the equipment.

## PROCEDURE

Collect the following data. In each particular case, three measurements should be made and the average used in the data analysis.

Measure the length of time required for the ball to roll down the inclined track to the intersection of the tracks. Start from rest at a point 20 cm from the intersection. (Use a pencil point to hold the ball in place in order to ensure greater accuracy in the position of the ball and that it starts from rest.)

Measure the length of time required for the ball to roll from the intersection of the tracks to the other end of the horizontal track when the ball starts from rest at a point 20 cm from the intersection of the tracks along the inclined track.

Repeat both measurements using distances of 40, 60, 80, and 100 cm from the intersection along the inclined track instead of 20 cm.

## DATA ANALYSIS

Divide the distance the ball rolled down the inclined track by the time taken for the ball to roll down the inclined track to find the average velocity of the ball while it was being accelerated.

Divide the entire length of the horizontal track by the different lengths of time taken for the ball to roll along the entire length of the horizontal track to find the final velocity of the ball after it has been accelerated.

Plot the following graphs and indicate what relationships exist, if any:

1) The distance the ball rolled down the inclined track against the time taken to roll down the inclined track.
2) The distance the ball rolled down the inclined track against the time squared.
3) The distance the ball rolled down the inclined track against the velocity of the ball along the horizontal track.
4) The distance the ball rolled down the inclined track against the square of the velocity of the ball along the horizontal track.
5) The time the ball took to roll down the inclined track against the velocity of the ball along the horizontal track.

The average velocity along the horizontal track should be double the average velocity along the inclined track. If your results do not indicate this give a reason for the experimental error. Does the error become less as the distance the ball rolls down the inclined track increases? Why?

Since the slope of the track does not change, the acceleration should be the same for all runs. Determine the acceleration for each run and indicate which value you feel to be most accurate. Why?

## QUESTIONS

1. A car is traveling along a road at a steady speed. It passes an unmarked police car parked beside the road. The police car accelerates, overtakes the speeding car, passes it, and signals it to stop. Make a sketch graph showing the speeds of the two cars plotted against distance.

2. An automobile is driven from Atlanta to Washington, D.C., a distance of 600 miles, in 16 hours. Calculate the average velocity.

3. On February 20, 1962, American Astronaut, John Glenn orbited the earth three times, a distance of 75,000 miles or more in 4 hours and 56 minutes. Compute the average velocity of his capsule in m.p.h., ft/sec, and m/sec.
4. In order to become air-borne, a small plane must attain a velocity of 80 m.p.h. If the average acceleration is 5 $ft/sec^2$, compute the time required for the take-off run.

## NEWTON'S LAWS AND MOMENTUM

In the previous experiment, we measured the velocity and acceleration of a moving body. In this experiment, we will study two of the three laws concerning forces which were first formulated by Newton. We will also deal with a further concept involving motion. It may be thought of as the "quantity of motion" and is called linear momentum.

Sir Isaac Newton (1642-1727) developed the three laws which explain the way bodies behave when acted upon by forces. These three laws are usually referred to by their number and may be stated as follows: the First Law - an object at rest will remain at rest and an object in motion will remain in motion in a straight line unless it is acted upon by an external force; the Second Law - when a force acts on an object, the object will experience an acceleration that is directly proportional to the size of the force and in the same direction as the force; and the Third Law - when one object exerts a force on another object, the second exerts an equal force on the first and in the opposite direction. In this experiment, we will see examples of Newton's First and Third Laws.

It is necessary that we understand the differences between mass and weight before we can fully comprehend the consequences of these laws. The concepts of these properties of matter are clear. Mass refers to the amount of matter in a substance and is determined by the ability of the substance to resist changes in motion. The amount of matter in a substance, or its mass, would not change from one place in the universe to another. Weight is a measurement of the gravitational force applied to a particular mass and would change from place to place. The weight of an object is slightly heavier for an object in Alaska than it would be in Washington, D.C., due to the slightly different radius of the earth. The weight of an object on the surface of the earth would be six times the weight of the same object on the surface of the moon, but we must realize the object would have the same mass.

This should make it clear that different units must be used to represent mass and weight. The confusion which exists between mass and weight is caused by the common usage of the same units to represent both concepts. Since weight is directly proportional to mass, the difference in weight of an object at different locations on the surface of the earth is so slight that it is not ordinarily noticed. Consequently, the inertial characteristics of mass are consistent with weight on the surface of the earth. We must realize, though, that weight itself is a characteristic of mass and is related to the inertial characteristics of mass in the following manner:

$$W = mg$$

where g stands for the acceleration due to gravity at the surface of the earth. Since g is a constant in this case the weight would only hold true for objects at the surface of the earth.

In this experiment, we will be studying some inertial characteristics of mass. Realize the same observations could be made at any place in the universe even though the weight of the objects involved might be drastically changed.

Linear momentum is defined as the product of the mass and velocity of a body and is often written as

$$p = mv$$

where p stands for the momentum. Thus, a small object moving rapidly may have the same "quantity of motion" as a large object moving slowly. One of the most interesting features of linear momentum is that, in a collision between two or more objects, linear momentum is conserved. That is, if two objects collide, the sum of the momenta before the collision is the same as the sum of their momenta after the collision.

In this experiment, we will investigate linear momentum by use of an air track. This is a device consisting of a long, hollow, metal track with holes along it which is connected to a source of compressed air. This allows a small, metal object - referred to as a "car" - to ride on a cushion of air so that the effects of the forces of friction are reduced. (The result of the reduction of the frictional forces is that the "car" has even less friction between it and the track than the friction forces between your feet and an icy sidewalk.) Therefore, we can use this device to investigate some of the properties of moving bodies without having to worry about or compensate for the effects of friction.

This experiment will be presented as a demonstration as we only have one set of equipment per laboratory room. Sufficient time will be available, however, for you to operate the equipment yourself after the demonstration has been completed.

## PROCEDURE

To illustrate Newton's First Law use a mass with springs attached to each end. It can be demonstrated that the mass will stay at rest and/or move in a straight line until a force is applied. This force for the moving mass may be the spring at the end of the track that reverses the direction of motion of the mass.

To illustrate Newton's Third Law use a large spring bumper and start with the spring attached to only one of the masses. Bring two equal masses together at the middle of the track with the air turned off and the spring completely compressed. Turn on the air and observe that each mass has an equal and opposite velocity. Repeat with the large spring attached to both of the masses so that they will oscillate when the air is turned on. Repeat for unequal masses. How does the action of unequal masses differ from the action of equal masses? Explain the reason for this.

To illustrate that linear momentum is conserved determine the velocity of a mass before collision and the velocity of the two masses after collision. The masses are integral multiples of each other by comparative lengths so, for simplicity, the smallest mass may be designated 1 unit of mass and the larger masses as multiple units. Velocities may be determined by timing between two or three of the support rods on the apparatus before and after collisions. Start with elastic collisions between equal masses. Place one mass at rest near the center of the track. Set the second mass in motion by bouncing it off the spring at the other end of the track and time its velocity immediately before collision with the first mass. Then, time the velocity of the first mass after collision. Is momentum conserved? Explain. What is the momentum of the first mass before collision? What is the momentum of the second mass after collision?

Repeat this experiment using unequal masses. In some runs have the initially moving mass greater than the rest mass and in some runs have the rest mass greater than the initially moving mass. What is the result when the moving mass is greater than the rest mass? What is the result when the rest mass is greater than moving mass? How do the results of collisions between unequal masses differ from collisions between equal masses?

To illustrate inelastic collisions replace the springs on the masses with velcro tape in such a manner that upon collision the masses will stick together. Using various arrangements of masses calculate and record the momenta of the masses before collision and after collision for seven different combinations. Does momenta seem to be conserved? What could explain any differences you might have observed?

## QUESTIONS

1. A 3000 lb car is moving 30 mph down the expressway. It is hit from behind by a 5000 lb truck moving 50 mph. If the bumpers stick together, how fast are they moving after the collision?

2. A father and his son are standing together in the middle of a pond covered with very slippery ice. The father is twice as heavy as his son. How can the father get his son to shore? How can the father get to shore?

3. Two small boys are roller skating on a sidewalk. The first boy weighs 80 lbs and is moving at 9 ft/sec. The second boy weighs 100 lbs and is standing still. They collide. If they both do not fall down, but hold on to each other, how fast will they be moving.

4. Gravity on the surface of the moon is 1/6 the gravity on the surface of the earth. If two cars collide on the surface of the moon compare the extent of damage to the cars with a similar collision on the surface of the earth.

5. Which of Newton's laws is best illustrated by a person being forced back in an automobile seat as the car rapidly accelerates? Explain.

6. Why do football coaches usually want fast halfbacks for broken-field running and heavy fullbacks for line plunges? Explain in terms of Newton's laws and momentum.

# VECTORS AND THE RESOLUTION OF FORCES

In the world of physics, as well as in your daily life, there are many times when it is convenient to specify not only "how much" or "how far", but also "in what direction". Quantities which have this characteristic of possessing both a magnitude and a direction are known as vector quantities. In working with such things as displacements, velocities, accelerations, and forces, we find it convenient to work with vector quantities since they not only have a magnitude but also have a direction. (Quantities such as mass, length, time, money, and temperature have only magnitude and are known as scalar quantities).

The concepts of velocity and acceleration are vector quantities. In speaking of velocity, we are concerned with direction as well as magnitude (or speed). For example, it is not sufficient to get from Atlanta to Birmingham by travelling 60 mph, you must also be travelling in the proper direction (in this case, probably west on I-20). A similar concept occurs with acceleration. If a car is travelling north at 60 mph and is accelerated 10 mph/second for one second, its velocity will change by 10 mph in the direction of the acceleration. If the acceleration is in a northerly direction, the car will be moving 70 mph; if southerly, it will be moving 50 mph.

To work with vector quantities, it is often convenient to use a graphical method. A line with an arrowhead (also called a vector) is used. The length of the line is drawn to some scale to represent the magnitude of the vector, while the orientation of the line and the arrowhead indicate the direction. (Both the scale for the magnitude and the orientation for the direction are chosen arbitrarily to fit the given situation.) For example, a velocity of 60 mph east might be represented by a line 6 cm long pointing to the right as illustrated in Figure 1. In this case, the scale is 1 cm - 10 mph and the direction "east" is to the right.

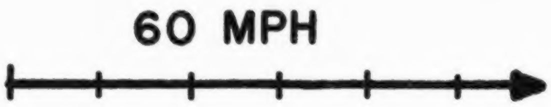


Figure I.

When working with vector quantities, it must be remembered that they possess a direction as well as a magnitude. Thus, a "lost" little boy who has wandered 3 blocks north, 2 blocks west, 1 block south, 2 blocks west, 1 block north, 1 block east, 4 blocks south, and 2 blocks east is not really sixteen blocks from home. How many blocks must he walk to get home? How far is he from home? Explain the difference between these questions.

An example of how vector quantities are added is given in Figure 2. Displacements of 4.0 miles east, 3.0 miles N 30°E, 2.5 miles S 60°W, 3.5 miles N 15°W, and 2.5 miles S 75°W have been added together to get the resultant or sum of the vectors ( 4.1 miles N 1°E ). The sum is the vector that goes from the tail of the first vector to the head of the last vector (and is shown in the diagram as a dotted line for convenience). This method for adding vectors worked with any number of vectors representing any type of vector quantity (velocity, force, etc.) and is known as the "head-to-tail" method:

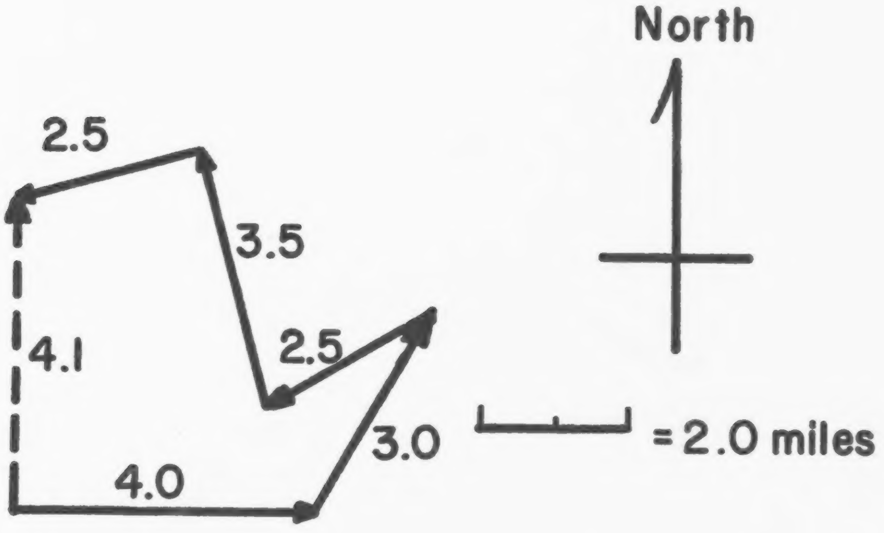


Figure 2.

Another method, for adding only two vectors at a time, is known as the parallelogram method. To add vectors using this method, the vectors are drawn with their tails together to form two sides of a parallelogram. The parallelogram is then completed and the diagonal drawn from the tails of the vectors to the opposite corner of the parallelogram is the sum of the vectors. Note the addition of the 5 lb force and the 4 lb force in Figure 3. Compare Figure 3 with the addition of the same two vectors using the "head to tail" method in Figure 4. (Be sure to ask your instructor if you do not understand how to use both of these methods and how they work.)

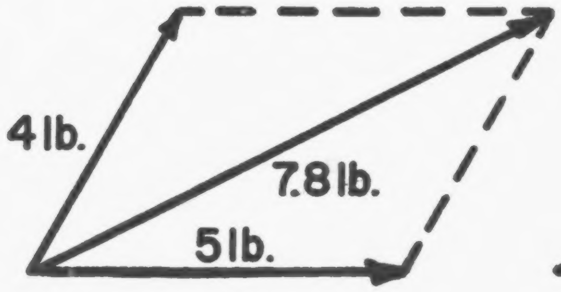


Figure 3.

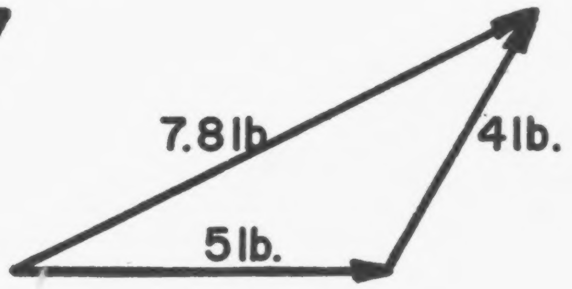


Figure 4.

In contrast to adding vectors together to get a resultant, it is sometimes helpful to reverse the process and "break a vector down" into a number of other vectors known as components. The most common "breakdown" is into two components at right angles to each other. In Figure 5, the vector F has two components, $F_1$ and $F_2$, which are perpendicular to each other. If F represents the force you are exerting on the handle of a lawnmower, $F_1$ would be the part of the force tending to push the lawnmower into the ground and $F_2$ would be the part of the force tending to move the lawnmower forward.

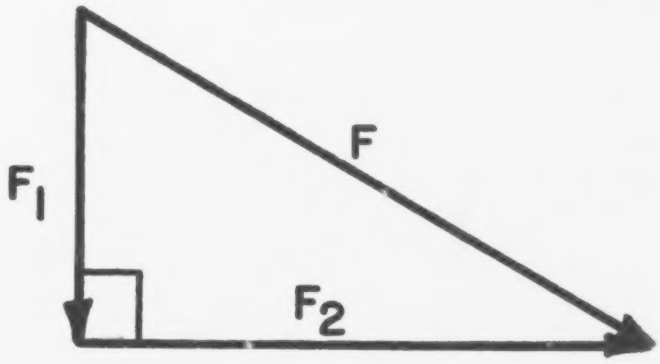


Figure 5.

In this experiment, we will be using a circular table with movable pulleys attached to the edges of the table. If the weights (forces) suspended from the pulleys are in equilibrium, the ring to which the weights are attached should remain stationary in the center of the table. An example of this is a flag tied to the center of a rope used in a tug of war. If the opposing forces are of the same magnitude, but in opposite directions, the flag will remain stationary. If the forces are not in equilibrium, the flag will be moved. By knowing the vector forces (both magnitude and direction) of all forces but one, we can determine the vector force needed to cause the system to be in equilibrium.

## PROCEDURE

Mount a pulley on the 20° mark on the force table and suspend a total of 100 grams over it. Mount a second pulley on the 120° mark and suspend a total of 200 grams over it. Draw a vector diagram to scale, using a scale of 20 grams per centimeter, and determine graphically the direction and magnitude of the resultant by using the parallelogram method.

Check the result of your diagram by setting up the equilibrium on the force table. This will be a force equal in magnitude to the resultant, but pulling in the opposite direction. Set up a third pulley 180° from the calculated direction of the resultant and suspend weights over it equal to the magnitude of the resultant. Cautiously remove the center pin to see if the ring remains in equilibrium. Before removing the pin, make sure that all the strings are pointing exactly at the center of the pin; otherwise, the angles will not be correct.

Mount the first two pulleys as before with the same weights as before. Mount a third pulley on the 220° mark and suspend a total of 150 grams over it. Draw a vector diagram to scale and determine graphically the direction and magnitude of the resultant. This may be done by adding the third vector to the sum of the first, which was obtained previously. Now set the equilibrant on the force table and test it as before.

Clamp a pulley on the 30° mark on the force table and suspend a total of 200 grams over it. By means of a vector diagram drawn to scale, find the magnitude of the components along the 0° and 90° directions. Set up those forces on the force table as they have been determined. These two forces are equivalent to the original direction. Test the system for equilibrium. Where should the two pulleys be placed to test for equilibrium?

## QUESTIONS

1. An ant travels due east from its hole for a distance of four feet, then moves due south for 3 feet, then due west for four feet during a time interval of 30 seconds. What is its average speed? its vector velocity?

2. A person mowing his yard exerts a 30 lb force on the handle of the mower. The handle is at a 30° angle from the horizon. What is the vector force which causes the mower to move?

3. An automobile is driven 12 miles west and then 16 miles north in going from one city to another during a time interval of 45 minutes. What is the average speed of the automobile? its vector velocity? How far apart are the two cities?

EXPERIMENT
9

# ROTARY MOTION

For most people, the concepts of why an astronaut is "weightless", why water stays in the bottom of a bucket that is being swung around in a circle by its handle, and what happens to the water in a clothes dryer are much more complicated than the concepts that were encountered in our discussions concerning linear motion. If you recall the discussion concerning Newton's laws, it was found that the proper statement of the First Law of motion was that an object at rest would remain at rest and that an object in motion would remain in motion in a straight line unless some external force acted upon it. What we will be doing in this experiment is taking a closer look at what is meant by this law and what some of the consequences of it are.

It has been common to refer to centrifugal force as the primary force involved in rotary motion whereas in reality it is an example of Newton's Third Law which states that for every force there is an equal but opposite force. Centripetal force is really the unbalanced force which is involved in rotary motion. If it were not for centripetal force the matter in motion would stay in motion in a straight line. An example of this is the rotating bucket of water. The centripetal force is the force exerted by your hand upon the handle of the bucket. If the centripetal force were released, the bucket of water would go flying off in a straight line from the point of release if it were not for gravitational force being exerted on the bucket.

The force we feel being exerted on our hand by the handle of the bucket is in reality an equal but opposite force to the centripetal force exerted and is due to the inertial properties of matter. To clarify this, think of pushing a block of wood across a table. The unbalanced force causing the block of wood to move is exerted by your finger and could be compared to the centripetal force in rotary motion. The equal but opposite force exerted by the block of wood against your finger could be compared to centrifugal force. Possibly a clearer comparision would be some forces observed in an automobile. The force you feel against your back caused by the seat forcing you body to accelerate could be compared to centripetal force. The equal but opposite force exerted by your body against the seat could be compared to centrifugal force and is caused by the inertial qualities of your body.

Our senses are used to feeling the effect of a constant gravitational force. When conditions are such that the effect is not felt we experience "weightlessness". Imagine yourself in a very tall building and you are in an elevator falling at the same rate as your body. You would experience weightlessness in such a situation. A similar comparison could be made to an astronaut orbiting the earth. In other words, the same effects are observed in a free fall situation as would be observed far, far out in space where the gravitational forces become nil. Comparably, we can induce the feeling of an artificial gravity far, far out in space by causing the body to be accelerated. What would be a logical way to induce a feeling of gravity in a space ship?

The usefulness of a gyroscope is dependent upon the principles of rotary motion. In any observable matter there are tremendous numbers of atoms. These atoms can be thought of as individual little packets of matter obeying Newton's laws of motion. In a rotating wheel these individual packets of matter are located at various distances from the center of the wheel. This indicates the centripetal forces on these individual atoms will vary from atom to atom. The centripetal force on an atom at the outer edge of the wheel must be much greater than that on an atom close to the center of the wheel if both atoms make a complete revolution in the same time interval. Therefore, the centripetal force must increase as we get further from the center of the wheel and closer to the outer edge, IF THE PERIOD OF REVOLUTION IS A CONSTANT.

If the wheel is properly balanced, the centripetal forces are in equilibrium and centripetal force becomes more of an abstract concept of the binding force from atom to atom keeping the outer atoms from flying off in straight lines. Consequently, the inertial properties of matter become more apparent. When we attempt to change the direction of rotary motion, we find the resistance to change has been increased.

Just as we had a "quantity of motion", called linear momentum, when we investigated motion in a straight line that was observed, here we have a similar quantity that is called the angular momentum. This "quantity of motion" is the product of the mass, velocity, and also the perpendicular distance from the axis of rotation of the mass. It would be the sum of all of the little atoms which make up the mass. This becomes rather difficult to explain to a person with a limited background in mathematics, but the effects are easily demonstrated.

## PROCEDURE

At each table there is some equipment consisting of a small mass, a string, a piece of glass tubing, a paper clip, and some washers to be used as weights. The small mass is swung around in a horizontal circle above your head by inserting the string through the glass tubing. By changing the radius of the circle and the rotational velocity, the centripetal force needed to keep the small mass in orbit will vary. Do you have to increase or decrease the pull on the string when you increase the speed of the mass? Do you have to increase or decrease the pull on the string when the radius is increased? Explain. What happens if you let go of the string?

Adjust the radius of the string from the glass tubing to about 20 cm. Use a marker on the string before the glass tubing to keep the same radius while the small mass is orbiting. Using various numbers of washers as the centripetal force, record and plot the period of rotation against the number of washers (centripetal force). To determine the period of revolution, have a partner measure the time required to swing the small mass around 10 revolutions and divide the time interval by the 10 revolutions. Try plotting the frequency instead of the period. Try $F^2$. What relationships can be determined?

To demonstrate the conservation of angular momentum, have one partner stand on the circular platform holding a textbook in each hand close to his body. Start him in circular motion and observe what takes place as he extends his arms outward and then brings his arms back to their original positions. Explain how this indicates angular momentum is conserved. How can the rotating person slow his rotation himself without getting off the platform or touching any other object?

Observe the characteristics of a spinning gyroscope. Then have one partner hold a weighted bicycle wheel while he is standing still on the rotating platform. Set the bicycle wheel in motion and observe the action as the person changes the plane of the spinning bicycle wheel. What takes place when the plane of the bicycle wheel is changed?

## QUESTIONS

1. Explain why a centrifuge can separate materials in a fluid.

2. A boy sitting on the front edge of the back seat of an automobile holds a balloon filled with helium by a string. The car suddenly accelerates. What effect does this have on the boy? on the balloon? Explain why.

3. An unbalanced force causes acceleration. In which direction is acceleration taking place in rotary motion? What force causes this acceleration?

4. Does the moon exert a centrifugal force on the earth? Explain.

5. How does a game of "pop the whip" illustrate some principles of rotary motion?

6. Place some coins at various position on a spinning phonograph record. Which coins are more likely to stay on the record? Why?

7. Name three devices which utilize gyroscopes.

## EXPERIMENT
## 10

# HARMONIC MOTION AND THE SIMPLE PENDULUM

In this experiment, we will be investigating some of the properties of harmonic motion or motion that repeats itself according to a definite set of responses to forces acting upon the object in motion. Many of the objects and processes that exhibit regularity in time are found, when analyzed carefully, to obey the requirements for harmonic motion in one form or another. Objects that exhibit harmonic motion typically possess motion about some fixed position where there are no unbalanced forces acting upon it. As the object moves away from this point, the forces acting upon it tend to move the object back towards its central point. However, when the object returns to that point and the forces acting upon it that would cause it to move are zero once more, the object itself is already in motion so that it is carried past the point of zero forces and the *restoring forces* once again make it slow down and return to the central point once more from the opposite direction. In the absence of frictional forces, this motion would continue indefinitely unless some outside force were imposed to stop the motion.

When an object exhibits harmonic motion, the forces tending to return the object to its central position increase as the object moves further and further away from the central position. Objects that exhibit harmonic motion quite often will do so with the *same* period (or time required for one complete back and forth movement) under a wide variety of conditions. We will investigate two different types of devices that exhibit harmonic motion in the laboratory, and try to discover the factors that can and cannot influence or change the period of each of them.

To measure the period of something, we must first have a clear idea of how a period is defined and then realize what the definition implies when it is applied to measurements made at different positions along the path of the motion. The period of an object or process that is repeating itself is the time required for one complete *cycle* (the time that the same point is reached again *from the same direction as the direction from which you started measuring*). Thus, for a swinging pendulum, one period would be the time required for the end of the pendulum to swing from the top of its swing on one side to the top of its swing on the other side and *back again to the top of its swing on the first side.* It is not always convenient or accurate to measure a period with the starting point at the end of an oscillation, however. In the case of a moving pendulum, for instance, you cannot always be sure that the mass is at the top of its swing and not still moving upward or, perhaps, already moving downward. In this case, therefore, it is better to measure the period at the bottom of the swing when you can see that the line of the pendulum is parallel to the support post of the apparatus. However, there is a possible complication. The period will not be complete when the string is parallel to the support again. A complete period will have been reached when the line is parallel to the support and the mass is moving in the same direction that it was moving when you started the measurement. Your instructor will explain this important difference to you in greater detail.

The two pieces of equipment that we will be using in this laboratory will be the simple pendulum and a mass suspended from a steel spring. The simple pendulum consists of a large mass suspended by a relatively light string or line from some fixed point. An example of something that uses a simple pendulum is a "grandfather's" clock. An example of something that exhibits harmonic motion, using a spring that is stretched and relaxed while moving a weight, would be the hair spring and balance wheel in a regular watch or non-electric clock.

## PROCEDURE

The period of many harmonic motions is frequently a very small time interval. To reduce the percentage error in determining the period, it is convenient to measure the time interval for a number of periods and divide the total time interval by the number of cycles. The most common mistake made by students is to start counting with "one" at the same instant the stop watch is started. A little thought should indicate that a person should start with "zero" since "one" should not be counted until a full cycle is completed. In each of the following measurements, you should determine the time required for 10 complete cycles of the apparatus and by division, calculate the average time for one period or cycle.

In the simple pendulum there are only three basic variations that might affect its period — the length of the line, the mass at the end of the line, and the maximum angle the line makes with the vertical support (sometimes referred to as the horizontal displacement of the mass).

Using the heaviest mass and a horizontal displacement of 10 cm, measure the period of the pendulum for line lengths of 100, 80, 60, and 40 cm. From the information obtained plot graphs until a straight line graph is obtained. (Hint: An additional point you can use on a graph which you will not measure would be that for a length of zero cm, the period is zero seconds.) What relationship, if any, is determined?

Using a line length of 100 cm and the heaviest mass, measure the period of the pendulum for horizontal displacements of 10, 20, and 30 cm. What relationship, if any, is determined between length and displacement?

Using a line length of 100 cm and a horizontal displacement of 10 cm, measure the period of the pendulum for each of the different masses you have. What relationship exists, if any, between period and mass?

For a spring oscillator, there are only two variations we can make (other than changing springs). They are the vertical displacement and the mass on the end of the spring. Measure the deflection of the hook on the bottom of the spring in its unweighted position and when each of the masses has been added to the spring. (Do not let the spring oscillate.)

Using the heaviest mass, measure the period of the oscillation for vertical displacements equal to its complete deflection (as found previously), one-half of its complete deflection, and one-fourth of the complete deflection. Is the period the same for each displacement?

Using vertical displacements equal to one-half of the particular deflection for that mass, measure the period oscillation for each of the masses. Graph the information and determine what relationships between period and mass exist.

## QUESTIONS

1. A boy and a girl start swinging in similar swings at the same time. The boy weighs more than the girl. Soon the boy is swinging higher than the girl. Which one will complete more swings in the same time interval? Explain.

2. Give three examples of harmonic motion not mentioned in this exercise.

3. If an oscillating spring has a period of .18 seconds, what is its frequency?

4. What is the period of a tuning fork which has a frequency of 468 cycles/sec?

EXPERIMENT
11

## SOUND

Sound is caused by energy transfer as molecules strike molecules in a sudden compression. This energy is conducted in a wave motion of compression and decompression at speeds dependent primarily upon how close the molecules are to each other and secondly on the energy of the molecules themselves. This compression wave can be compared to the movement of compression down a coil spring as one end of the spring is suddenly hit.

Sound cannot travel through a vacuum since there are no molecules in a vacuum to transfer this mechanical energy. Sound travels faster through less dense gases such as helium than it does through heavier gases such as air. Sound travels faster through liquids than it does through gases, and faster still through crystalline solids than it does through liquids. We have used this characteristic of sound to theorize the internal structure of the earth by measuring the velocity of shock waves from earthquakes to various portions of the earth's surface.

In air, sound travels at approximately 1,100 ft/sec (or about 1 mile every 5 sec). This will vary depending principally upon the temperature. You might have noticed on a cold winter day a greater time lag between the time you saw an action producing sound and the time you actually heard it. We can roughly approximate how far lightning strikes by counting the seconds it takes from the time we see the lightning until we hear the thunder. You may also have observed this time lag in observing 4th of July celebrations with their fireworks displays.

For us to speak of the pitch, or frequency, of sound there must be a considerable number of compression waves uniformly spaced. The range of frequencies detectable to the human mind is between 20 vib/sec and 20,000 vib/sec. This range varies from person to person and usually decreases with age. It is not unusual for middle aged or older people to not hear frequencies above 10,000 vib/sec. Subsonic and ultrasonic refer to the range of frequencies below and above the frequencies detectable by the human ear. You might be familiar with ultrasonic whistles which are used to signal dogs, but which we cannot hear. You might also be familiar with the use of ultrasonic devices in cleaning certain mechanical parts and even clothes by the high speed agitation of molecules in liquids.

Very few pitches or frequencies are pure. When you strike a note on a piano you not only hear the basic frequency but you also hear overtones which are higher frequencies in multiples of the basic frequency. It is this arrangement of overtones which causes different peoples' voices to sound different even though they might be singing the same note. The size and shape of the cavities in a person's chest, throat, mouth, nasal passage, and sinuses cause different overtones to resonate and combine with the total sound produced. When we get a cold and liquids fill up our nasal passages and sinuses, our voices do not sound natural.

Overtones are due to resonance. We can illustrate resonance in several ways. Consider applying a push or a force against a swing (pendulum) synchronized with the natural period of the swing. It will swing higher and higher until the velocity of the swing matches the velocity of the push at the point the force is applied. In the same manner we can cause a tuning fork to vibrate by bringing a vibrating tuning fork of the same frequency close to it. The molecules of air will compress against the molecules of the tuning fork at its natural frequency. Cavities or tubes of particular sizes and shapes will have certain frequencies which will echo off one end of the cavity at definite intervals of the wave and will set up what we call standing waves. It is because of this principle that we build violins, guitars, and other musical instruments in the manner we do.

Because a wave is reflected in a reverse direction from which it came, the length of a resonating chamber will be odd 1/4 multiples of its resonating frequencies. The wave or compression must travel both directions which will be 1/2 multiples of the resonating frequencies. Since the wave or compression has been reversed by reflection, standing waves are produced. Standing waves are representative of resonance.

A wavelength is the distance between points of periodic motion where the wave motion begins to repeat itself. The wavelength may be measured from crest to crest or from trough to trough or from a point of zero energy to a similar point of zero energy (usually the second zero point) or from any point of the wave to a similar point where the wave begins to repeat its motion. The velocity of a wave could be determined by dividing its wavelength by the length of time it takes to repeat itself (its period). The formula $V = \frac{\lambda}{T}$

where $\lambda$ (lambda) represents wavelength and T represents the period is very similar to the familiar form of determining velocity $v = \frac{s}{t}$. Rather than working with period we more frequently speak of its frequency which is the reciprocal of the period or how many vibrations occur per second. Thus, the velocity of wave motion can be found by multiplying the wavelength by its frequency. $V = \lambda f$.

There are two types of sound waves — the longitudinal and the transverse. The former are those that cause the media to vibrate in parallel to the direction the wave is moving and the latter type is the one which causes the particles of a medium to vibrate at right angles to the direction in which the waves are moving.

Amplitude is a measurement of the intensity of the wave motion or the force of the compression. In sound we would measure amplitude in the loudness of the sound or in decibels. In a guitar it would depend on how hard we plucked a string; the string would still vibrate at the same frequency but its greater displacement from rest position will cause it to compress the air molecules it strikes with greater force.

Extremely loud noise can actually injure the ear. Years of exposure to intense sound for several hours everyday can lead to permanent hearing loss. Earplugs and helmets are often used by factory workers and airplane pilots, crews and mechanics. It is still a matter of intellectual debate whether the level of sound which is experienced by a person living downtown is actually injurious to health.

## PROCEDURE

Place each of the tuning forks, while vibrating, over the resonance tube and adjust the water level in the tube until the sound produced is loudest. Record the length from the top of the tube to the water level for each of the tuning forks and plot these lengths against corresponding frequencies on a graph. What type of relationship is suggested by the graph? Develop a straight line graph from this information. Assuming the distance measured represents 1/4 wavelength determine the velocity of sound in air for all tuning forks. ($V = \lambda f$). If your calculations indicate a different velocity for the sound produced by each tuning fork, explain what caused the error.

Place little pieces of folded paper over the wires of a sonometer. Place each of the tuning forks close to the wires and increase the tension of the wires by suspending weights to the wires. The papers will be agitated when the wire reaches the frequency of the tuning fork. Plot the weights (representing tension of the wire) against frequencies. What type of relationship is indicated?

Observe what takes place when a ringing door bell is suspended in a bell jar and a vacuum is induced. What caused the bell to become quieter as the vacuum increased?

## QUESTIONS

1. There is an interval of 12 seconds observed from the observation of lightning flashes until the thunder is heard. How far away is the lightning striking?

2. A person in the mountain shouts and hears his echo 4 seconds later. How far away is the reflective surface?

3. Sound travels approximately 5000 ft/sec in salt water (it varies with temperature). If the echo from a sonar impulse is heard 10 seconds after being emitted, how far is the object reflecting sound from the sonar equipment?

4. How is the sound associated with the musical group, The Chipmunks, produced?

5. If a resonating chamber is shortened, will this cause an increase or decrease in the resonating frequencies? Explain the nasal sound produced by a person with a head cold.

6. Compute the wavelength in centimeters of the broadcast wave from a radio station near your home. The frequency on which the station broadcasts is usually published in daily newspapers.

7. What makes a sound unwanted? And what can be done to get rid of unwanted sound?

EXPERIMENT
12

## ELEMENTS, MIXTURES, AND COMPOUNDS

In this experiment, we will be investigating how different materials can be combined and what these combinations mean. All of the materials in the world are made up of only 100 or so basic units called elements. These may be found in groups containing only the one element or one element may have combined with another element or elements in various ways. Atoms of some elements can be considered individual molecules although, frequently, atoms combine with atoms of the same elements or atoms of other elements to form relatively stable molecules. A compound is composed of similar molecules and the molecules are made up of atoms of more than one element. (An example would be when hydrogen and oxygen combine to form water which is most commonly found as a liquid on the earth and has entirely different properties than those of either of the two gases from which it was made.) If the substance is composed of more than one type of molecule, we refer to the result as a mixture. (An example might be the combination of salt and sand.)

Generally, there are two basic changes that a material can undergo - if we exclude nuclear changes in which the atoms themselves are changed. They are called physical changes and chemical changes. A physical change takes place when there in no change in molecular structure. On the macroscopic level, or on a large scale where things can be seen, this means that there may have been a change in the state or shape (from a gas to a liquid, etc.) of the material, but the molecular arrangement of the atoms is still the same. An example might be ice melting to form water. A chemical change takes place when there is a change in molecular structure. In this case, the material itself no longer exists, but there is a new material with different characteristics which has been formed. An example of this might be the changes which occur when a piece of paper is burned.

## PROCEDURE

Examine a nichrome wire and a strip of magnesium ribbon. Note their characteristics such as how elastic they are, brittleness, luster, hardness, and how easily they bend. Scratch their surface to determine whether they are the same luster beneath their surface or whether their outer surface might have oxidized.

Hold the nichrome wire in a flame and note the color; then let it cool. Examine it again to determine what changes, if any, have occurred.

Take the strip of magnesium ribbon in a pair of forceps and - while glancing at it out of the corner of your eye (DO NOT LOOK DIRECTLY AT THE BURNING MAGNESIUM RIBBON) - touch it to the flame. AFTER IT HAS STOPPED BURNING, drop the resulting material on a piece of filter paper. Suspend the powder in a test tube containing 5 ml of water, a piece of red litmus paper, and a piece of blue litmus paper and set it aside for later observation. How does the resulting material differ from the original strip of magnesium ribbon? How would you propose reforming the resulting material back into the original form of magnesium ribbon? Would you judge that the ash weighs as much as the original magnesium ribbon? What accounts for the difference in weight?

Place a small crystal of iodine (the size of a match head) in a test tube after examining it and heat it gently until a deposit is formed 1/3 of the way up the side of the tube. CAUTION: AVOID HAVING IODINE COME INTO CONTACT WITH YOUR SKIN OR CLOTHING. Allow the tube to cool and then heat the deposit again so that the deposit is reformed a similar distance further upward in the tube. What has occurred - a physical change or a chemical change? Explain what has happened to the molecules of iodine in this change.

Scrape the iodine back into the bottom of the tube. Obtain one drop of mercury in the tube and heat it carefully with the iodine. (AVOID INHALING ANY OF THE VAPORS GIVEN OFF FROM THE TUBE.) Cool and examine the contents of the tube. What has occurred - a physical change or a chemical change? Is the new substance an element, a mixture, or a compound? How does it differ from the original materials used? What suggestions do you have for reforming this new substance back into the original form?

Heat one spatula of sugar (sucrose) in a small, dry test tube until it turns dark. Was this a physical change or a chemical change? Where did the moisture come from that condensed in the upper part of the test tube?

Add 15 ml of water, a piece of red litmus paper, and a piece of blue litmus paper to a gas bottle. Place some sulfur in a deflagerating spoon (only enough to half fill the spoon). Hold the spoon in a flame until it starts to burn, lower the spoon into the gas bottle, place a glass plate over the opening of the bottle, and let the suflur burn until the flame is extinguished. What is the white smoke that is produced? Where have you ever smelled a similar odor? Gently shake the water in the gas bottle until some of the white smoke dissolves in the water. What changes take place in the pieces of litmus paper? Is sulfur a metal or a non-metal? Does this experiment suggest oxides of non-metals dissolved in water form acids? Explain.

Re-examine the test tube containing the magnesium ash suspended in water. What changes have occurred in the litmus papers? Is magnesium a metal or a non-metal? Does this experiment suggest that oxides of metals dissolved in water form acids? Explain.

Grind together in the mortar about two spatulas each of sodium chloride and sand. Transfer to a small test tube and add about 15 ml of water. Warm gently over a burner, then filter the mixture through a funnel fitted with a filter paper into a beaker. (If you do not know how to properly fold the filter paper, ask your instructor.) After it has drained, wash the residue on the filter and collect the wash water in the beaker containing the residue. (Residue is the solid collected on the filter paper and the filtrate is the liquid, or solution, that runs through the filter paper and has been collected.) Heat the contents of the beaker until it is barely dry. After it has cooled, examine by feel and taste the material in the beaker and the residue on the filter paper. What other mixtures can you think of which could be separated in this manner?

## QUESTIONS

1. What is the difference between an element and a compound?

2. What is the difference between a compound and a mixture?

3. What is the difference between a physical change and a chemical change?

4. Is distilled water an element, compound, or mixture?

5. Is quartz sand an element, compound, or mixture?

6. Is baking powder an element, compound, or mixture?

7. When you fry an egg, is this a physical change or a chemical change?

8. When wood is sawed, is this a physical change, or a chemical change?

9. When water freezes and bursts a pipe, is this a physical change, or a chemical change?

10. When a firecracker explodes, is this a physical change or a chemical change?

11. Is air an element, a compound, or a mixture?

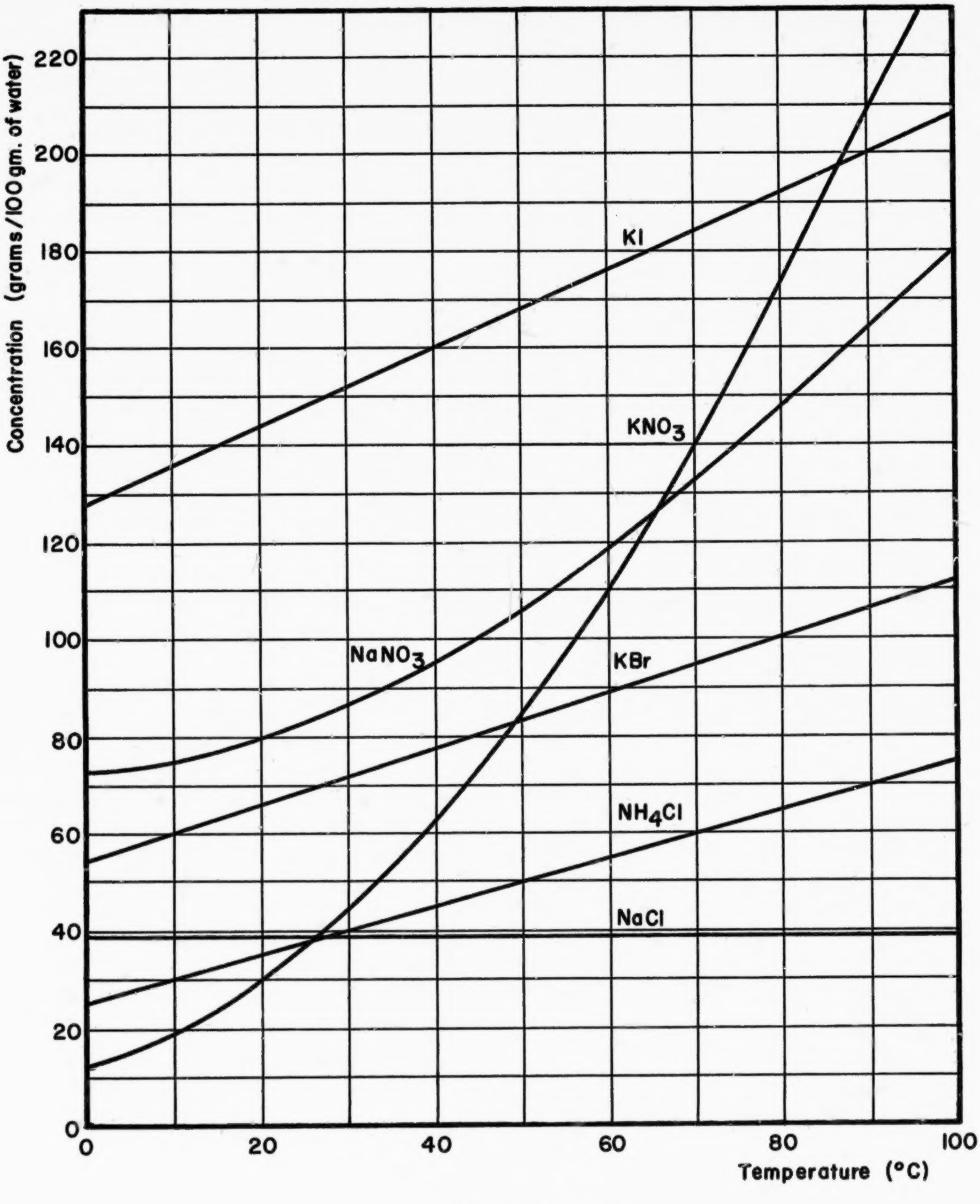
## EXPERIMENT
## 13

# SOLUTIONS

You are probably familiar with the fact that substances like sugar, salt, and soda dissolve in water. These and similar resulting mixtures are called *solutions*. You probably also have observed that the amount of material which may be dissolved into a solution varies within certain limits. *A solution may be defined as an homogeneous mixture of two or more substances in which the relative proportions may vary continuously within certain limits.* (A solution is like a mixture in that the proportion of the constituents is variable, and it is like a compound in that it is homogeneous.) Generally, if there is an obvious distinction between the two, the material that is dissolved is called the *solute* and the material that does the dissolving is called the *solvent*. The principal types of solutions are gas in gas, gas in liquid, gas in solid, liquid in liquid, solid in liquid, and solid in solid.

Solvents other than water are sometimes employed to dissolve substances, but water solutions are by far the most important class of solutions. It shall be our purpose in this experiment to study the physical and chemical properties of solutions, particularly those of water solutions, and to investigate the general properties of the more common types of solutions - such as, gas in liquid, liquid in liquid, and solid in liquid.

The solubility of one substance in another refers to the maximum amount of the substance that will dissolve in a definite amount of the other substance at a given temperature. In the case of solids dissolved in liquids, the solubility is the maximum amount of the solid that dissolves in 100 grams or 100 milliliters of the solvent at a given temperature. The *Handbook of Chemistry and Physics* usually lists the solubility in grams of solid (or solute) in 100 grams of solvent. A graph showing how the solubility changes with temperature for some different materials is shown in Figure 1. Note that the solubility of some solids is directly proportional to temperature within the limits shown on the graph, whereas others do not fit this simple relationship.



Solubility of Some Common Salts

Figure I.

The solubility of gases in liquids varies greatly with the nature of the solute and the solvent. For example, at $0^{o}C$ and standard atmospheric pressure, 1 liter of water will dissolve 0.02 liters of hydrogen gas, but it will dissolve 1175 liters of ammonia. Pressure also affects the solubility. Generally, the solubility of gases in liquids will increase with an increase in pressure, but an increase in temperature will cause the solubility of gases in liquids to decrease.

The animal life in our oceans and fresh waters depends on the oxygen dissolved in the water for life. Cold water can contain more oxygen than warm or hot water. Consequently, there is more animal life in our temperate waters than at tropical latitudes. Seals and whales are found in our colder waters because they have more animal life to feed on in the colder waters. An interesting side effect caused by the amount of air dissolved in water is its taste. Water with oxygen dissolved in it tastes sweeter than unoxygenated water. You might have noticed water being aerated in municipal water systems as it is sprayed up into the air. The oxygen dissolved into the water serves two purposes. It purifies the water by oxidizing any impurities and it makes the water taste better. The taste of water can be clearly shown by bringing some water to a boil to drive out the air and then drinking the water after it has been allowed to cool. You will find the water now tastes flat.

A pair of liquids, which completely dissolve in each other in all proportions, is said to be completely miscible. If, when you are adding one liquid to another, you reach a point at which no more of the liquid you are adding will dissolve in the other liquid, the two are said to be partially miscible. If one of the liquids will not dissolve in the other in any proportion, the two are said to be completely immiscible.

Water is one of the most unique substances found on the earth. One of its unique characteristics is its ability to dissolve, to some extent, so many other substances. It is called the universal solvent. Our oceans contain a variety of dissolved salts and minerals. The abundance of the salts and minerals will vary depending upon their solubility and the amount of salts and minerals available in the crust of the earth to be dissolved. Even though the salt content of the oceans is fairly high, it still has not reached its saturation point.

Normally, as long as we can dissolve more of the substance into the liquid, the solution is said to be unsaturated. When a point is reached where as much of the substance is being precipitated out of solution as is being dissolved, we say the solution is saturated. An increase in temperature will usually increase the amount of substance that can be dissolved. (How does this differ for the solubility of gases in liquids?) It is possible for a solution to contain more of the solute than it would in ordinary conditions. We call such a solution supersaturated. For example, by heating water we can dissolve much more sugar into it than we could at lower temperatures. If we are careful in lowering the temperature gradually and not allowing any impurities into the solution, it is possible to retain the sugar in solution at lower temperatures. If we then drop a crystal or impurity into the solution, the excess sugar molecules will begin to come out of solution and cause the seed crystal to grow, or they can come out in the form of many crystals.

## PROCEDURE

Heat about 25 ml of water to boiling and allow it to cool gently to room temperature. Divide this into equal portions in two test tubes. Shake one tube vigorously for about a minute. Place the two tubes in a beaker of boiling water and note any changes taking place. In which tube do bubbles first start appearing? What effect did shaking the tube have?

Fill a test tube about one-third full of water. Add a small piece of Alka Seltzer tablet to the water in the test tube. What happens? When the bubbling has ceased completely, place the test tube in a beaker of boiling water and again observe the contents of the test tube. What conclusions can you come to?

Place 5 ml of water in a small test tube. Add one drop of ethyl alcohol and shake the tube. If the alcohol dissolves in the water, add several more drops of alcohol and shake the tube. What is the limit, if any, to the solubility of alcohol and water. What can be said about alcohol and water in terms of miscibility?

Repeat the above procedure with water and ether, water and carbon tetrachloride, alcohol and ether, and alcohol and carbon tetrachloride. What can be said about these combinations in terms of miscibility? (CAUTION: Dispose of these liquids by pouring them into the sink and flushing with considerable water. Keep flame away from these liquids and from the sink into which they have been poured.)

In three separate test tubes, place 0.5 gm each of magnesium sulfate, potassium chlorate, and calcium sulfate. Add 10 ml of water to each tube. Shake the tubes frequently over a period of 10-15 minutes. To these tubes in which the solid dissolves completely, add 2 or 3 more 1 gm portions of the solids and shake between additions. Do this until no more solid appears to dissolve. Which salt is most soluble? Which is least soluble?

Dissolve 8 gm of sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 3 ml of water by heating the mixture in a test tube. Heat until complete solution results. Insert a plug of cotton in the mouth of the tube and allow the solution to cool to room temperature. If no crystallization takes place, the solution should be supersaturated - that is, it contains more dissolved material than a saturated solution at the same temperature. After the tube has cooled, remove the cotton plug and add a small crystal of sodium thiosulfate. (NOTE: You have to be careful to be sure that you have enough sodium thiosulfate in the original solution and not too much water for this portion of the experiment to work at all.)

## QUESTIONS

1. In terms of miscibility, what could be said about water and vinegar? water and liquid soap? water and oil?

2. What other good solvents can you think of besides water and alcohol?

3. What conditions must be met to get as much carbon dioxide to dissolve in water as possible?

4. Suppose you had a saturated solution of $NaNO_3$ and a saturated solution of NaCl at 100°C and then cooled them both to 0°C. What difference would you observe in the test tubes? (Use Figure 1.)

EXPERIMENT
14

# SEPARATION OF MIXTURES

The separation of the constituents of a mixture can be accomplished if there are significant differences in the physical and/or chemical properties of the substances in the mixture. These differences may be in solubility, in boiling point, in freezing point, or other physical or chemical properties. We will look at some of these methods of separation in this experiment.

A mixture of a solid dissolved in a liquid (a solution) may be separated by the process of distillation. A mixture of two or more liquids in which the components have widely different boiling points may also be separated by the distillation process. The distillation process successively separates out materials by boiling the material with the lowest boiling point temperature out of the mixture first. The solution is placed in a closed container and heat is applied. As the material with the lowest boiling point turns to a gas, it rises in the container and is sent out through the side of the container near the top into a cooler chamber than the original container. In the second chamber, the gas is condensed back into a liquid and allowed to flow into a collection chamber by the force of gravity. The collection chamber may then be replaced by another one and the process repeated for the material with the next lowest boiling point if needed.

In another technique, paper chromatography, we may use various solvents to separate substances on filter paper. If the end of a strip of filter paper is dipped into a liquid, the liquid will be drawn into the filter paper by capillary action. As it travels up the paper, the liquid comes into contact with the water on the surface of the cellulose fibers which make up the paper. If a small sample of an organic material soluble in the liquid has been placed ("Spotted") near the lower end of the paper, the organic material will be swept along the moving liquid. Here, the material will actually be dissolved in the moving liquid.

Each of the dissolved organic materials (solute) will move in a given solvent a definite distance which is proportional to the distance moved by the solvent. Thus, each solute has a constant, called an $R_f$ value, which is characteristic of the solute for the particular solvent. The $R_f$ value is defined by the equation:

$$R_f = \frac{\text{Distance solute moves}}{\text{Distance solvent moves}}$$

Hence, an unknown within a mixture may be identified by experimentally determining its $R_f$ values for several solvents and comparing them with known $R_f$ values.

Paper chromatography can be used to separate colored and colorless substances that cannot easily be done by other methods, such as distillation. The technique of paper chromatography has been used in separating sugars, inorganic ions, proteins, etc. Chromatography has also been shown to be of considerable value in the separation of nonactive, toxic components of antibiotic preparations from active, nontoxic components - even when the chemical structures were unknown.

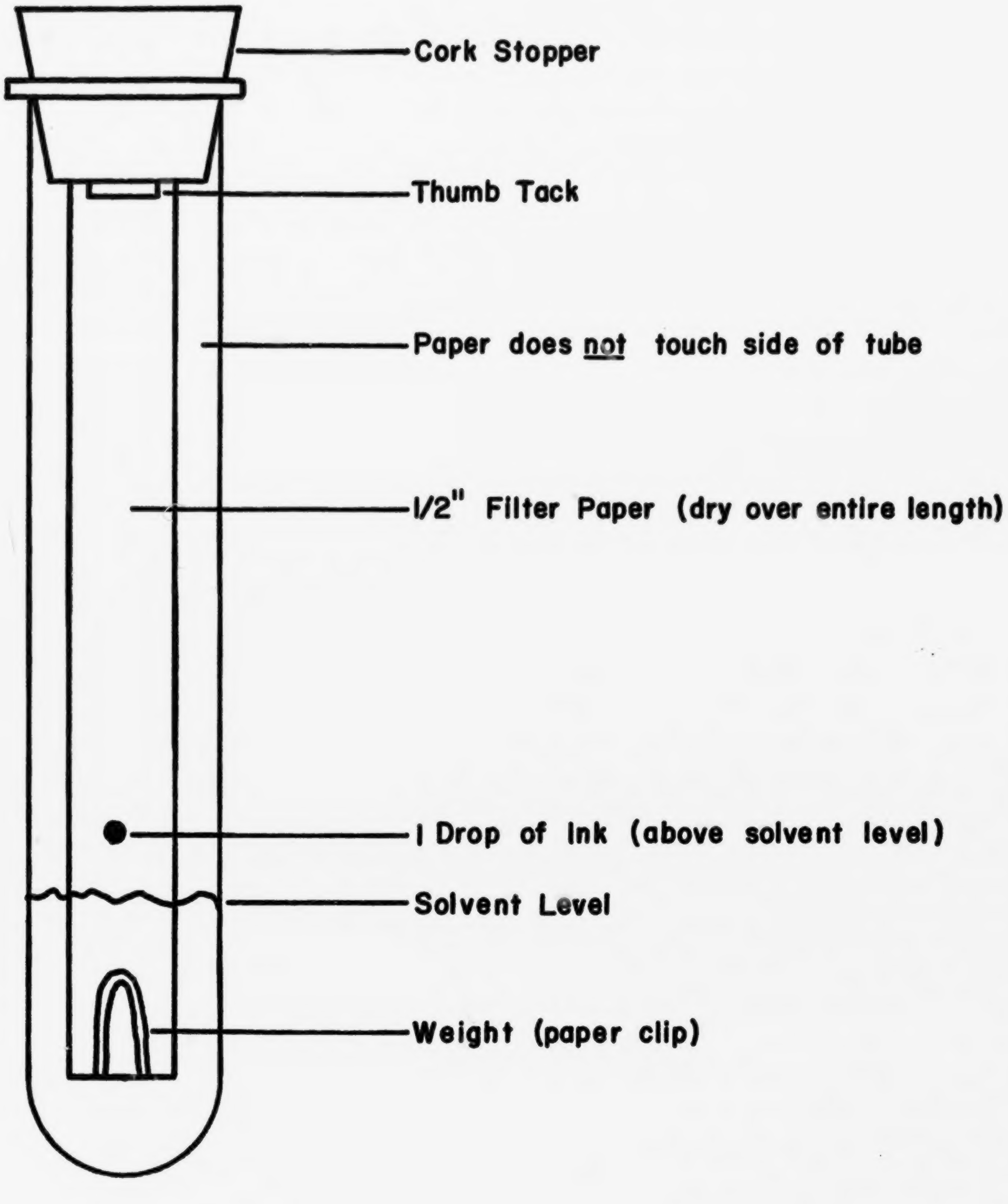
If a mixture contains dissolved soluble substances, the soluble substances may be changed to insoluble substances by chemical processes to cause precipitation, thus effecting a separation of the dissolved material. Many solutions contain dissolved ionic substances, such as calcium salts, magnesium salts, and acids like hydrochloric or sulfuric acid. The presence of these salts and acids in ordinary tap water makes the water "hard" and unable to lather easily with soap - which itself is a sodium or potassium salt of a high molecular weight acid. These dissolved ionic substances may be precipitated from their solution by a suitable substance which will form an insoluble compound with the dissolved ions. There are a variety of substances which will act as "water softeners", and a good soap itself is one of these. A good soap will, through chemical reaction, form a precipitate (scum) in the water and, in addition, effectively maintain its lathering properties.

## PROCEDURE

Several distillation processes are set up in the laboratory. One mixture being distilled and separated is a solution of potassium permanganate in water. Make a sketch of the apparatus for this distillation, and read and record the temperature and pressure at which the water is being distilled out of the solution. Examine each of the other distillation apparatuses and make sure that you understand how and what each is doing. What causes the steam to condense back to water? How can you tell this method separates the water from the potassium permanganate?

Washable black ink is composed of many different-colored constituents. Your problem is to separate all of these by the process of paper chromatography. The solvents available are water, methyl alcohol, 50:50 water -- methyl alcohol, and ethyl alcohol. Place approximately 10 ml of the solvent in a large test tube.

## Apparatus for Paper Chromatography


Cork Stopper
Thumb Tack
Paper does not touch side of tube
1/2" Filter Paper (dry over entire length)
1 Drop of Ink (above solvent level)
Solvent Level
Weight (paper clip)

**NOTE:**

1) Avoid handling the paper unnecessarily. Finger marks and skin oil are undesirable.

2) Make pencil marks to record the location of the ink spot and the solvent level.

Figure 1.

Cut strips of filter paper 1/2 inch wide as long as the tube and with a point at one end. Place 1 drop of ink on the filter paper 1 inch from the pointed tip. Make a small pencil mark on the side of the filter paper to show the location of the ink drop. Tack the filter paper to a cork stopper so that the tip of the paper just dips into the solvent when the paper and stopper are placed in the test tube. Refer to Figure 1. The chromatography process is allowed to continue until the solvent has reached within 1 inch of the cork stopper or until optimum separation has occurred. Remove the filter paper and allow it to dry. Note the position of the solvent level on the paper and mark it with a pencil. How many different substances can you identify? Can you put the substances back together again and make black ink? Cut out each of the colored sections, and put each one in a separate test tube. Add between 1/2 and 1 ml of water to each test tube. Do the colored substances dissolve? Pour the liquids from all three test tubes together into one test tube. What color do you get?

Dissolve several thin shavings of soap in a flask containing about 25 ml of distilled water, by shaking, to form soap solution. Pour a portion of this solution into two separate test tubes, filling them about three-quarters full. To one test tube add a few drops of hydrochloric acid. Note the formation of a precipitate. Filter the precipitate and wash it with a little cold water on the filter paper. Place the precipitate in a third test tube, add 5 ml of distilled water, and shake vigorously. Compare this with the original soap solution in the second test tube. What differences can you see? What conclusions as to what the precipitate is composed of are suggested?

To the second test tube, add three ml of one molar calcium chloride solution. Observe what happens. What conclusions can you come to?

## QUESTIONS

1. Why can alcohol be separated from water by distillation?

2. Give two examples of industrial use of distillation.

3. Give an example of industrial use of precipitation.

4. Which two methods would be more likely to be used in commercial processes? Why?

EXPERIMENT
15

## STATIC ELECTRICITY

Electrical phenomena was first described by the ancient Greek scientists. They discovered that certain materials, when rubbed together on a dry day, developed unusual properties. Like materials repelled each other and unlike materials attracted each other. For example, when a material called amber was rubbed with fur, it was attracted to the fur, while the separate hairs on the piece of fur repelled each other. You may have observed some similar reaction when you have taken off a wool sweater in the winter time. This was the result of a number of electrical charges building up on one material leaving an insufficient number of electrical charges on the other material.

Previously, you learned that chemical compounds resulted from the sharing of the outer electrons in atoms so that the atoms were tightly bound together to form molecules that had different properties than any of the atoms that made up the molecules. These same outer electrons are what we make use of when we work with electricity and, in the case of batteries, the energy that is supplied to these electrons is derived from changing these chemical bonds to form new compounds with new chemical bonds.

If the outer electrons in an atom are only loosely bound to the atom, they will be free to move about in the material and the material is referred to as a conductor. If the outer electrons are tightly bound to their atoms so they cannot move about easily, then the material is referred to as a dielectric or an insulator. In general, metals are the best conductors and nonmetals are the best insulators.

The electrical effects that we will be observing today develop only in insulators. When one material is rubbed with another, some of the electrons on the outer layers of the material are "scraped" off onto the other material. Since the rest of the electrons in the material are not free to move about easily in either of these two materials, there is a resulting excess of electrons on one of the materials and a deficit (or lack) of electrons on the other material. The forces between electrons are such that you may think of electrons as trying to stay as far away from each other as possible and also as trying to get to where there is an insufficient number of electrons. Therefore, materials with an extra amount of electrons or a lack of electrons repel each other while a material with an extra amount of electrons is attracted to a material with a lack of electrons.

When investigations were being made concerning the nature of these forces and phenomena, but before their actual nature had been determined, it was found necessary to differentiate between these two types of electrical charges (what we know today as an excess or lack or electrons). The charge received by a piece of hard rubber that has been rubbed with fur was arbitrarily assigned the name "negative" charge and the charge on the fur was assigned the name "positive" charge. It has since been learned that the rubber receives the extra amount of electrons, so that we have had to call the electron a negative charge.

While insulators produce static electrical effects on their surfaces, conductors may be used to store and/or transport the extra charges (or lack of charges). Since the outer electrons in the atoms of a conductor are free to move, they are attracted to a positively charged body and are repelled by a negatively charged body. If a conductor is touched to a charged body, the flow of charges to or from the conductor will neutralize the charge on the body and leave the conductor with the electrical charge (which will then flow to other conductors or through the air until, finally the original body with the opposite charge is also neutralized).

## PROCEDURE

Rub the hard rubber rod briskly with the piece of felt and then bring the rod close to the two pieces of wadded aluminum. What happens? Allow the wads to touch the rod. What happens now? Insert the rod between the two wads. Explain why the wads behave differently than originally.

Touch the wads with your fingers and repeat the process as before, Explain what must have transpired when the wads were touched by your fingers.

Whip the glass rod against the piece of silk cloth and repeat the process using the glass rod rather than the rubber rod. How does the action of the wads compare with the previous experiment?

Charge one of the wads of aluminum with the charged rubber rod. . Is the wad now repelled by the rubber rod? Bring the charged glass rod near the wad. Is the wad repelled by the glass rod? What conclusions does this suggest?

By properly placing a pair of conductors and insulating them form each other, it is possible to construct an "electron ferry" using a charged rod and one of the wads of aluminum. The arrangement of the materials is shown in

Figure 1. When the rod is brought near one of the conductors, the wad of aluminum should move back and forth between the two conductors. Explain the action of the wad.

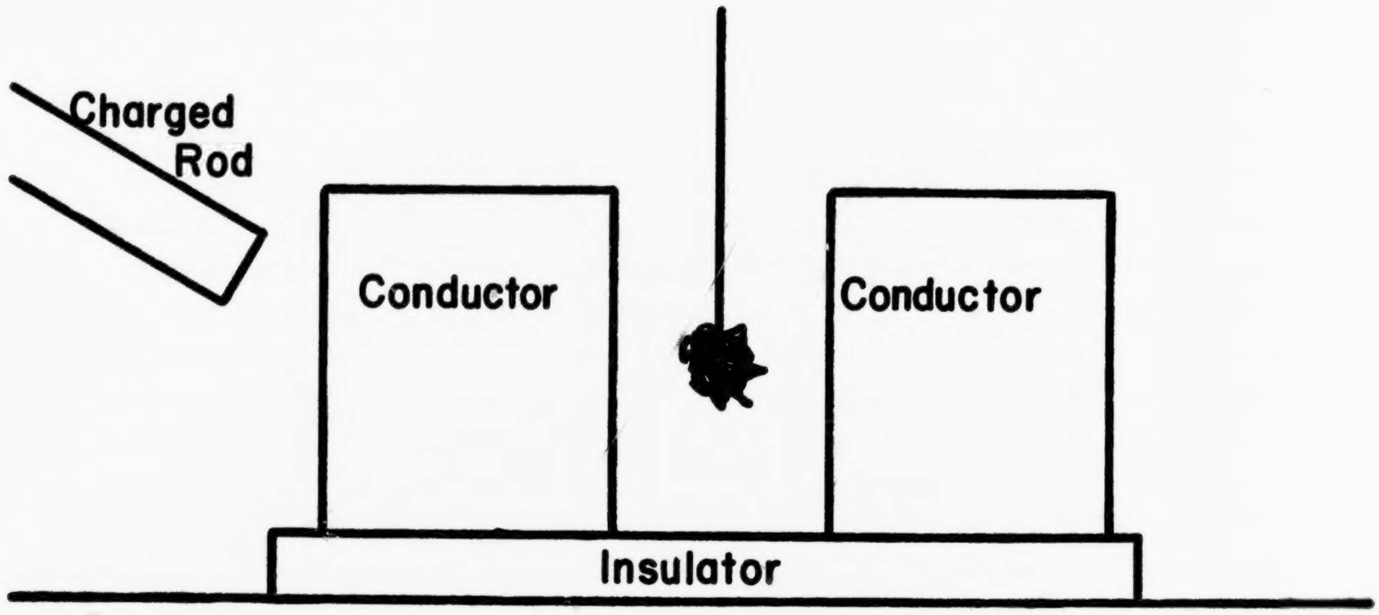


Figure I.

It has been found that charge developed on the rubber is a negative charge. Draw sketches showing the location of the charges on the different materials in each of the following:

a) Before and after the rubber rod touched the wads of aluminum. Show the charges on the rod and the wads and also show the motion of the wads.

b) The charges on the aluminum wad before the glass rod touched the wad and after the glass rod touched the wad. Also show the motion of the wad.

c) The charges on the rod, the two conductors, and the wad of aluminum for the motion of the wad in each direction illustrating the reason for the "electron ferry" to behave as it did.

With the information you have been given and the material at hand, determine the type of charge developed on the sphere of the Van de Graaf generator. Explain your reasoning.

QUESTIONS

1. In rubbing across some automobile seat covers we sometimes develop static electricity. How can we determine the type of charge developed by us? developed on the seat covers?

2. Nylon clothing frequently becomes charged with static electricity. What are some ways you can suggest to discharge this static electricity?

3. Static electricity can be dangerous if allowed to develop on gasoline trucks. What methods are used to prevent static electricity developing in such situations?

4. Since plastic and nylon develop static electricity, what can you say about their conductivity?

5. Does lightning indicate that static electricity has developed in our atmosphere? Explain.

6. Is the force exerted by the plastic hair comb on the bit of paper as great as the gravitational force exerted by the earth on the paper?

7. What evidence can you cite to say that an object has a positive or negative charge? Justify.

EXPERIMENT
16

## ELECTRICAL CIRCUITS

Electrical circuits and systems are basic ingredients in modern technology. Many things that you come into contact with every day operate directly from or are controlled by electrical power in some manner. It is doubtful that there is any energy in existence that you will utilize more than electricity in your life time. It, therefore, becomes important that you come to understand it better.

You learned in the previous experiment that electrical phenomena result from motion of electrons as they are repelled or attracted and caused to move from place to place. The positive charges are associated with nuclei of atoms. Since the nuclei are so massive in comparison with the electrons, it is the movement of electrons that is so important in most electrical phenomena. When there is a concentration of electrons the object becomes charged negatively. When there is a scarcity of electrons the object becomes charged positively since there is a greater concentration of positive charges associated with the nuclei than is neutralized by orbiting electrons.

Frequently, two objects can both be charged negatively in comparison with a neutral object, but one might be charged more negatively than the other. In this case, the object of lesser negativity will be referred to as positive in relation to the object of greater negativity. If the objects are touched to each other there will be a flow of electrons from the object of greater negativity to the object of lesser negativity until they each have an equal concentration of electrons. Two objects which are both positively charged can be referred to as positive and negative with respect to each other. What will happen if two such objects are touched to each other?

Benjamin Franklin, in his work with electricity, theorized that electricity was some type of invisible fluid and he came to the conclusion, through some experiments he conducted, that this "fluid" flowed from a point of greater positive charge to a point of lesser positive charge. He referred to this flow of "fluid" as an electrical current. The concept of electrical current flowing from positive to negative is still taught in our textbooks even though we now realize the only movement which takes place is the movement of electrons from points of greater negativity to points of lesser negativity (or positive points).

A force must be applied to cause this electron movement. We might think of this electromotive force (emf) as both repulsive and attractive. Since like charges repel each other, there is a repulsive force between the electrons and a high concentration of electrons will cause them to spread out. If they are contained in a good conductor, such as a copper wire, some of the electrons will be forced down the wire causing current. If, on the other end of the wire, the electrons are being taken off rapidly a positive charge can be developed. The attraction of opposite charges is also a force and this attractive force of unlike charges can also create an electrical current.

We measure current in amperes which is the measurement of a specified number of electrons moving past a point in the circuit every second. The force causing the current is measured in volts. Just as in other types of force, we can have an electrical force without movement. Another point that probably should be made clear is that voltage or emf is a relative measurement of how the electrical force at one location compares to the electrical force at some other location. Unlike water pressure gauges, a voltmeter will not indicate the electrical pressure at any one location but will only indicate the difference in electrical pressures between two locations.

A common measurement in electricity is watts. It is the product of the electrical force in volts and the current measured in amperes. Watts is a measurement of the ability to do work. It has been defined as

1 watt = 1 volt x 1 ampere

It is common to charge customers for the electricity they use for so many kilowatt-hours. This would refer to how many watts, measured in thousand watt units, were utilized for one hour.

Since the atoms in a conductor have to be continuously resupplied with electrons in order for a current to flow, we must have a continuous loop of wire from the source of electrical energy to the device to which the energy is being supplied and back to the source of electrical energy. This continuous loop is called a closed or complete circuit. You will discover that, if you do not have a closed circuit when you connect together the different components used in this experiment, you will not get the expected results when the switch is closed.

## PROCEDURE

Connect a wire from one end of a battery to one end of a switch, a wire from the center of the switch to one end of a socket, and from the other end of the socket to the other end of the battery. Be sure that the metal part of the wire is connected rather than the outer covering of the wire in each case. When the switch is closed, the bulb should light. Draw a diagram of the circuit. Observe the brightness of the bulb. Can you make it dimmer without turning it off? Now, push one of the wires connected to the battery through the clip so the outer covering only is touching the clip. Close the switch. What is the purpose of the outer covering?

Remove one of the wires from the battery and connect the second battery to the circuit by connecting the wire that you removed from the first battery to the same end of the second battery and a second wire between the other ends of the two batteries. Be careful to connect the circuit so you have the wire connecting the two batteries attached to the opposite ends of the batteries. This arrangement of batteries is called a series connection. Close the switch. Draw a diagram of the circuit. How does the brightness of the bulb compare with the previous experiment? What conclusions can you come to from this comparison?

Remove the second battery and repeat the arrangement you first started with. Add the second battery to the circuit by connecting a wire from one end of the second battery to the same end of the first battery and connecting a second wire between the other ends of the two batteries. This arrangement is called a parellel connection. Close the switch. Draw a diagram of the circuit. How does the brightness of the bulb compare with the previous experiment? What conclusions can you come to from this comparison?

Put the batteries in series, again, and add a second bulb in series with the first. Close the switch. Draw a diagram of the circuit. Does the brightness of the bulb suggest the current flowing through the circuit is the same as flowed through one bulb when one battery was in the circuit? Unscrew one of the bulbs. What happens to the other bulb? Why?

Remove the second bulb and reconnect it in parallel with the first. Close the switch. Draw a diagram of the circuit. Compare the brightness of the bulb with some other arrangement. Unscrew one of the bulbs from the circuit. What happens to the other bulb? Why? (Ignore any change in brightness.)

In many homes, a light or wall outlet is wired in such a way that a light can be turned on or off by changing the position of either of two switches. That is, either switch can be used to turn the light on if it is off and off if it is on. See if you can wire such a circuit using two switches, one battery, and one bulb. Draw such a diagram. (HINT: For this part, you will have to make the switch connections at each end of the switch as well as the center clip, and you will have to move the switch completely from one side to the other to change its position.)

QUESTIONS

1. Are the lights in our homes wired in parellel or series? How can you tell?

2. What is the difference between direct current and alternating current?

3. Edison started out supplying direct current to users. Why have we converted to alternating current for commercial use?

4. Why is it that we can touch the charged sphere on a Van de Graaf generator with a voltage of several thousand volts and it would not be as dangerous as grounding conventional 110 volt wires?

5. If electricity costs $0.20 per kilowatt-hour, how much would it cost to burn a 100 watt bulb three hours?

6. Why does the bulb glow more brightly when two or three batteries are used instead of one?

7. Describe the effect on the current in the bulb if we change the length of wire to three or ten times its original length.

EXPERIMENT
17

# ELECTRICAL INDUCTION

In the nineteenth century, a number of scientists made important discoveries concerning the relationship between electrical phenomena and magnetic phenomena. These relationships are what we will be investigating in this experiment.

They discovered that a current through a wire produced a magnetic field around the wire, and that, conversely, if a wire is passed through a magnetic field, an electromagnetic force is generated in the wire which will cause a current to flow in a closed circuit of which this wire is a part. The direction of the magnetic field and/or the electromotive force produced in this manner is always such that the effects they produce will oppose (or counteract) the effects that produced them in the first place. This work has allowed scientists and engineers to develop other sources of electrical power than those produced by chemical action. The modern hydro-electric power plant was developed directly out of these discoveries.

Electricity may flow through a wire in one of two manners. If it flows in one direction only, it is called direct current. Batteries produce direct current. Direct current generators are becoming more and more rare these days. If the current flows first in one direction, then in the opposite direction, and repeats this cycle over and over again, it is called an alternating current. Alternating current is the type of current produced by most of the commercial generators and is used to provide electrical power to homes, etc.

We presently theorize that a moving electrical charge develops a magnetic field around it and an increase in the number of moving charges increases the strength or intensity of the magnetic field. There is an inertia associated with magnetic fields. To illustrate the effects of this inertia, consider electrons beginning to flow through a circuit as a switch is closed. Until the magnetic field is developed to its full strength, the movement of electrons is resisted by the inertia of the developing magnetic field. Once the magnetic field is developed there is no observable effect upon the electrons until the circuit is broken. Even though the electrons now have no electromotive force to cause them to move, the magnetic field tends to keep the electrons moving in the same direction until the field completely collapses.

It might help to think of the interaction of moving electrical charges and magnetic fields as the fields develop and collapse as an equal but opposite force. It is possible to effectively retard the flow of current in what we call choke coils. Choke coils usually have an iron core so a strong magnetic field can be developed. In alternating current (a. c.) circuits the electrons have a resistance to movement caused by the developing magnetic field. As the current reverses and the magnetic field collapses, any change in movement of electrons is resisted by the inertia of the collapsing magnetic field.

Choke coils are utilized to cut-out high frequency signals to certain speakers in hi-fi sets. Even though there is a time lag in developing and collapsing magnetic fields, we must realize that it is only a small fraction of a second. Would choke coils be effective in d. c. circuits? Why?

This same principle can be used in developing an electrical current. By subjecting a conductor to a magnetic field an opposing force between the electrons and the magnetic field will cause the electrons to be moved in one direction for a short period of time. Once the electrons have adjusted to the magnetic field there seems to be no continuing effect upon the electrons. By rotating a loop of wire in a magnetic field, it is possible to cuase the electrons to be shifted or moved back and forth in the loop of wire to develop an alternating current in the loop of wire. The commercial generators we use to develop electricity utilize this principle as they alternately shift the movement of electrons in the conductor 120 times per second. Why are our commercial a. c. circuits called 60 cycle circuits?

This principle is also used in developing transformers. A transformer usually has two coils of wires, not connected with each other, wrapped around the same core of iron. The purpose of the iron is to enhance the magnetic field produced. With a transformer we can increase or decrease the voltage by the relationship of number of turns the two coils have to each other. The number of turns will determine the quantity of electrons affected by the magnetic field. When the number of turns on the output side of a transformer exceeds the number of turns on the input side the voltage is increased and we call such a transformer a step-up transformer. What must be the relationship of turns in the transformers we use to control model trains? Would such transformers be called step-up transformers or step-down transformers?

## PROCEDURE

In order to have as little damage done to the equipment (AND YOURSELVES) as possible, be careful to follow these instructions very carefully. If you are in doubt about any of the instructions get them clarified by your instructor before preceeding.

Connect the power supply to the "straight wire apparatus" at each table. Turn on the current to the maximum value that your instructor tells you to use. Take the small magnetic compass and move it around the wire. Does the pointer of the compass line up parallel to the wire or perpendicular to it? Does the pointer of the compass always point in the same direction or does it change direction as the compass is moved from above the wire to below the wire and from side to side? What conclusions can you come to in regard to the configuration of the magnetic field?

Reverse the connections to the power supply and repeat the observations with the magnetic compass. What differences do you notice? What conclusions does this experiment suggest?

Disconnect the power supply and repeat the observations with the magnetic compass. How does the pointer behave? What effect is the wire having on the compass?

Connect a coil of wire to a galvonometer. Quickly insert one end of a bar magnet into the coil of wire. What action of the meter is observed? Leave the bar magnet stationary in the coil of wire. What action of the meter is observed? Quickly remove the bar magnet. What action of the meter is observed. When did electrical current seem to be produced?

Reverse the end of the bar magnet and repeat the above experiment. How did the action of the meter differ from its previous actions? What conclusions can you draw from this?

Try moving the bar magnet in and out of the coil of wire at various speeds. How can you obtain the greatest reading on the meter? Adjust the movement of the bar magnet to the natural frequency of the needle in the meter. Now move the bar magnet very rapidly in and out of the coil and compare the deflection of the meter. Does this mean there is less current induced? Explain.

Connect the small coil of wire to the meter and the large coil of wire to the power supply. Place a switch in the circuit containing the power supply and the large coil of wire. Place both coils of wire on the iron frame of the transformer apparatus. Close the switch while watching the meter and observe the deflection of the meter. Keep the switch closed and observe the meter. Open the switch and observe the meter. When was current induced in the coil of wire connected to the meter?

Reverse the connections on the power supply and repeat the above experiment. What differences do you observe in the meter? What does this suggest to you?

## QUESTIONS

1. Would transformers be more likely to be found in a. c. circuits or d. c. circuits? Why?

2. What is meant by "electrical induction"?

3. Would the transformers seen on electrical poles in residential areas be step-up transformers or step-down transformers?

4. Since an electric motor works due to an interaction between current and magnetic fields, could we develop an electric current by turning the shaft of an electric motor? Give an illustration of a commercial device which demonstrates this.

EXPERIMENT
18

## LIGHT

The purpose of this experiment is to give you some idea of a few basic phenomena which occur when light interacts with material substances. In particular, in this experiment, we will study the phenomena of reflection, refraction, diffusion, diffraction, absorption, polarization, and interference.

The reflection of light is very similar to the reflection of water waves on a beach or shore. As each part of the wave reaches the shore, it is reflected in such a way that the first part of the wave to reach the shore will be the first part to leave. If the wavefront is approaching the shore at an angle, the portion that is on the left-hand side of the incoming wave will turn out to be on the right-hand side of the outgoing wavefront. A series of wavefronts striking a reflecting surface at an angle (called the angle of incidence) will leave the surface at an angle (called the angle of reflection). THE ANGLE OF INCIDENCE IS EQUAL TO THE ANGLE OF REFLECTION. These properties are illustrated in Figure 1, where the solid lines represent the incoming wavefronts and the dotted lines represent the outgoing wavefronts.

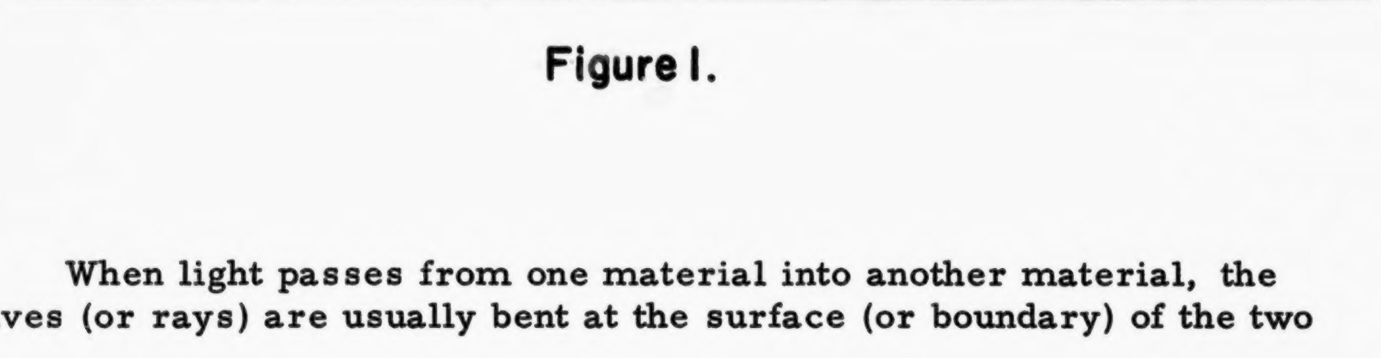


**Figure I.**

When light passes from one material into another material, the waves (or rays) are usually bent at the surface (or boundary) of the two materials. This is known as refraction and is the result of the speed of light changing to accommodate the material through which it is travelling. We can observe that the light rays are bent by placing a glass square on a piece of paper and allowing light from a source to shine on the edge of the glass as shown in Figure 2.

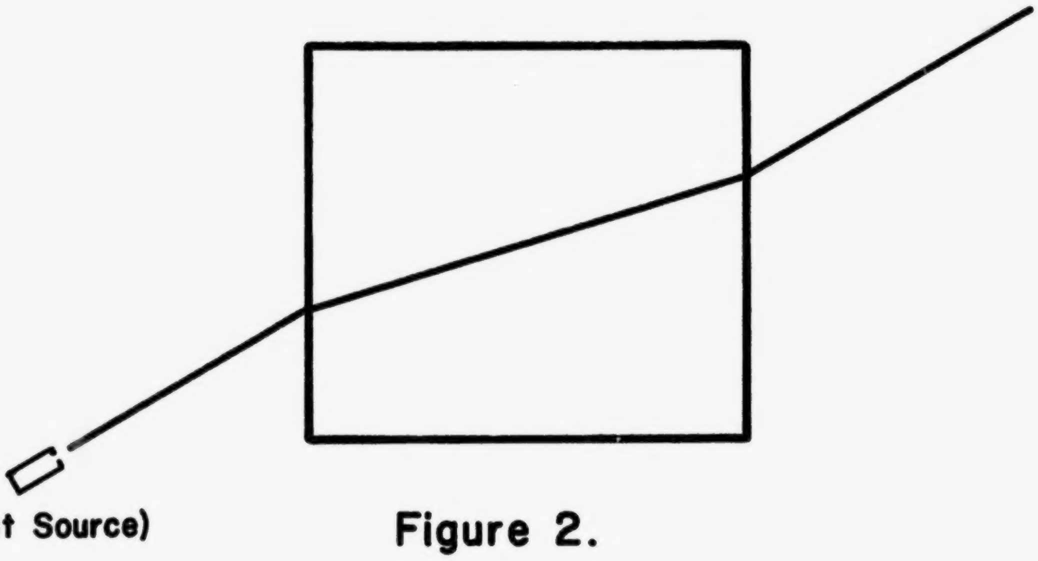


**Figure 2.**

Diffusion occurs when the light rays are "spread out" in the material. This happens because the individual rays of light are bounced off of the particles in the material so that they go off in different directions than the original direction of the beam. An example of this effect that you may have seen before is the way that the headlights of a car do not work as well in the fog as they do otherwise because light from the bulbs is spread out through the water particles of the fog and there is not as much light left in the original beam to light up the road.

Diffraction refers to the bending of light as it passes by the edges of opaque bodies or in being reflected from ruled surfaces. This bending of light called diffraction becomes very noticeable when light is sent through narrow slits to produce fringes of parallel light and dark bands or colored bands. Diffraction, like refraction, refers to the bending of light but for quite different reasons. The effects are similar to some extent but the differences are so apparent that diffraction and refraction should never become confused. In refraction the higher frequencies are bent the most while in diffraction the lower frequencies are bent the most. With diffraction, it is much easier to spread the spectrum of light over a larger area and thus make it easier to analyze the absorption or emission of particular frequencies by various substances.

Absorption occurs when the light rays are "soaked up" by the material so they cannot penetrate the material completely. There are many examples of this effect that you run across every day. They range all the way from regular sun glasses which absorb a portion of the light that enters them to the effects of a material like the bricks in a wall which absorb all of the light not reflected from the surface. Actually, the reason that things have colors is that they absorb all of the colors present in the light except the one which is allowed to pass through or is reflected from its surfaces. Thus, a piece of red cellophane absorbs all of the light except the red light and the red light is either reflected off of the surface so that it looks red from the outside or the red light passes through it so that when you look through it, everything seems to have a red color.

Light has properties similar to that of a transverse wave (it oscillates back and forth as it moves along much the same way that a water wave moves up and down as it moves along toward a shore). It can either move up and down or back and forth as it moves along its direction of motion and it may have still further things happen to it as it passes through a material. One such effect that we will look at in this experiment is something called polarization. Some materials have the property that they absorb almost all of the light waves that move back and forth in one direction while allowing most of the light that is moving back and forth at right angles to that direction to pass through without being affected. These materials are referred to as polarizing filters. An example would be the plastic lenses in "Polaroid" brand sun glasses. Other materials can actually change the direction in which the light moves back and forth when it passes through the material. In this experiment, we will investigate some of the effects of these two different types of materials.

There are certain characteristics of light waves which can be compared to water waves. When the crest of one water wave meets the trough of another water wave the level of the water is not affected, assuming the intensity of the waves was the same. When two crests meet or when two troughs meet, the displacement of the water level is enhanced. This characteristic of wave motion is called interference and is termed destructive interference in the first example and constructive in the second example. There are several examples of light behaving in this manner and diffraction is one of the best examples. The fringe patterns we see in diffraction are caused by the destructive interference of waves out of phase with each other producing dark bands and waves in phase with each other producing bright bands of light or color.

The speed of light in a material depends both upon the material that it is passing through and the color of the light. (The effect is due actually to the frequency of the light waves and our eyes detect different frequencies of light as different colors of light.) Different speeds mean that light of different colors will be bent through different angles as it passes into and out of the material. This property of light can be demonstrated by the use of triangular shaped piece of glass called a prism as illustrated in Figure 3. (Sir Isaac Newton used this kind of equipment in the 1660's and 1670's to develop his famous theories about light, color, and the composition of white light.)

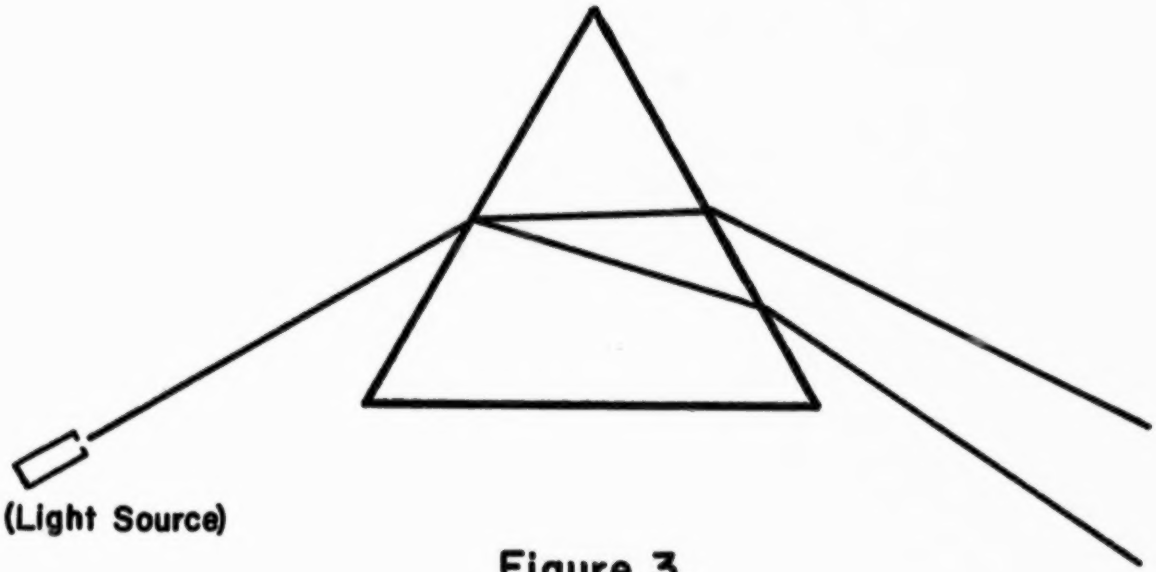


Figure 3.

When light passes through a prism and is broken up into its component colors, we call the result a spectrum and we refer to the branch of science that deals with measurements of a spectrum as spectroscopy. By means of making measurements to determine the exact colors of the resulting light, it is possible to find out what kind of material made the light and what is happening to the material while the light is being made.

While prisms could be used for this work, scientists have found it more convenient and accurate to use a different method to split a ray of light into its separate colors. This is done by means of a grating which utililizes the principles of diffraction and interference. The advantages of diffraction over refraction in analyzing the spectrum have been discussed before.

PROCEDURE

Place the flat mirror in its holder on the back of the data sheet. Draw a line along the front edge of the mirror to show its location on the sheet. Place a pin next to the center of the mirror. Place another pin about 2 inches from the mirror and 1 inch to the side of the first pin. By looking into the mirror, you can now see two pins. Move your head to the side so that the reflection of the pin that is away from the surface of the mirror appears to have moved behind the pin that is next to the surface of the mirror. Place another pin 2 inches from the mirror along this line. Since light moves in a straight line in a continuous material, the pins now represent the path a ray of light would take in going from either of the pins, to the mirror, and back to the other pin. Draw two lines from the pins that are away from the mirror to the pin next to the mirror. Measure the angles between each of these lines and the line showing where the mirror was placed. See Figure 4. Are they the same? Could reflection off the back part of the glass mirror rather than the front cause any error? Explain. What does this experiment illustrate?

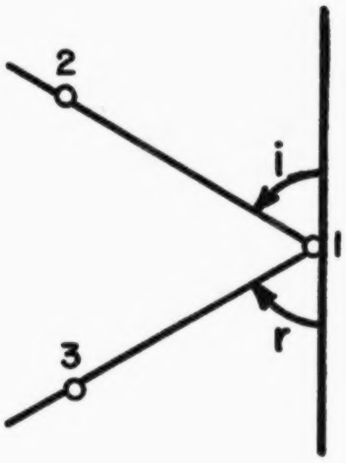


Figure 4.

Place the square of glass on the back of the data sheet and draw a line around it to show its location. Place a pin next to one side of the plate. Place a pin about 2 inches from the side of the plate and about 1/2 inch to the side of the pin that is already in place. Look through edge of the plate from the opposite side. Move your head so that the pin that is farthest away from the plate seems to move behind the pin next to the plate. Place a pin at the edge of the plate in line with the images of the other two pins and a fourth pin along the line away from the plate. (All four pins should now seem to lie along a straight line when you are looking at them through the plate.) Draw the three lines between the pins showing the path of the light. Extend one of the lines from the pins on one side of the plate across so that it is next to the line on the other side of the plate. See Figure 5. Is the projected line from the first two pins parallel to the line through the last two pins? What does the experiment illustrate?

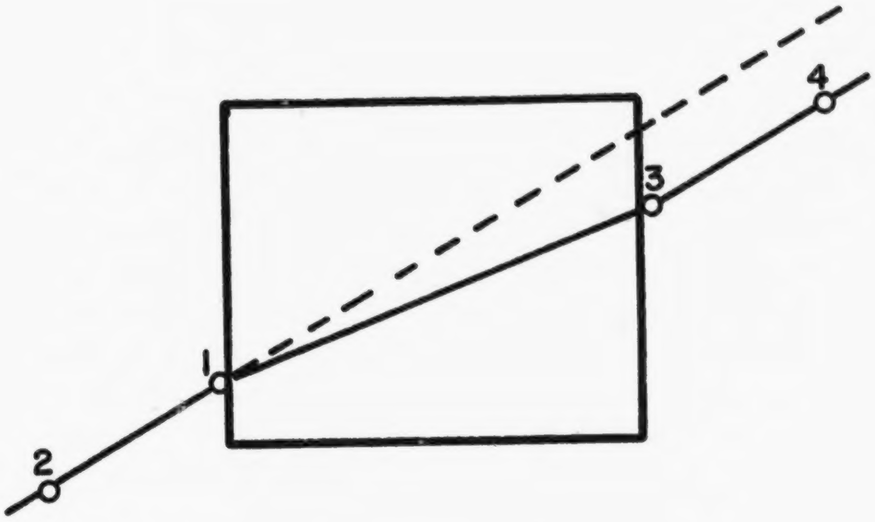


Figure 5

Place a paper clip in the cup on the table when the cup is empty. Move back from the cup so that you can just not see the paper clip. Without moving, having someone else add water to the cup slowly. Does the paper clip become visible? Draw a diagram to represent a light ray from the paper clip to the eye which would explain what happens to cause this.

On each of the tables, there is a group of colored cellophane sheets mounted in cardboard holders and a red paper card. Observe what happens when you try to read the printing on the card while look at it through each of the cellophane sheets in turn. Why does the white writing disappear and the black writing stand out clearly when looking through red cellophane? Why does the black writing disappear and the white writing become visible when looking through the blue and green cellophane?

The two plastic sheets mounted in cardboard at each table that are a light gray color are polaroid filters. Test their properties by holding up the sheets so that the arrows on each of them are upright and look through them both at one of the lights in the room. Now, rotate one of them about 90° slowly and observe what changes occur in what you can see through the two sheets. Explain what happens to cause the change in the amount of light which can get through the filters.

Hold the two polaroid sheets in one hand with the arrows pointing in the same direction and insert the "strain analyzer" between them with your other hand. Squeeze the two sides of the strain analyzer together and observe what happens to the polarization of the light passing through the first filter, then the plastic piece, and finally the second filter. Draw a diagram of the strain analyzer representing your observations.and explain why dark spots appear on the strain analyzer.

Hold the prism in one hand and align it so that the light from the fluorescent light enters at about the angle shown for the source in Figure 3 and so that your eye is at about the position where the light is shown to be leaving the prism. Rotate the prism slowly back and forth and - when you can see the spectrum from the light - describe the colors that you can see. Which color is bent the most? Which color is bent the least?

Hold the grating with the arrow upright against your eye and look at the fluorescent light. How does this spectrum differ from the one you saw through prism?

## QUESTIONS

1. If you saw a coin at the bottom of a swimming pool while you were at the edge of the swimming pool, would the coin be between you and its image or on the other side of its image?

2. When you look in the rear view mirror of an automobile at a following car, what side of the automobile does the driver appear to be sitting? When he passes you on the left, why does the image in the mirror also go to your left?

3. Explain what must take place to cause leaves to appear different colors to us at different times of the year?

4. What simple test could you perform to be sure that a rack of advertised polarized sunglasses are actually polarized?

5. Polarized sunglasses reduce the glare from reflected light more so than ordinary sunglasses. What does this suggest about the characteristics of reflected light?

## LENSES

As explained in the previous experiment, light refracts or bends when it enters or leaves different materials at an angle other then perpendicular to the surface of the material. The double convex lens illustrated in Figure 1 could be compared to two prisms placed together in such a way the refracted light converges. Such a lens is found in the human eye, cameras, and projectors and will give a real, inverted image when the light is projected onto the retina of the eye, film, or a screen as illustrated in Figure 2. A plano-convex lens as illustrated in Figure 3 would also do the same thing although the focal length would be longer.

Figure I.

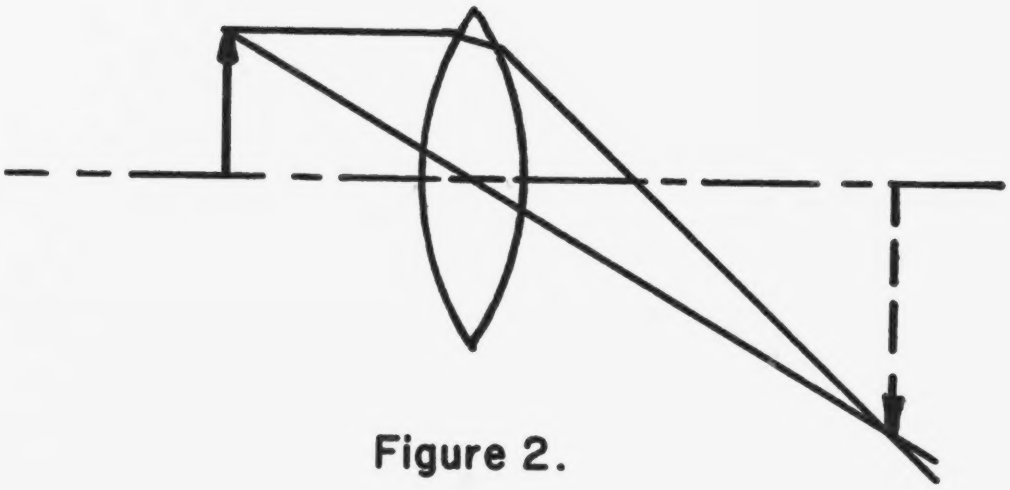


Figure 2.

Figure 3.

When the double convex lens is thick, its surface is more curved and light rays will be bent to a greater degree than through a thin lens. In the human eye, we have muscles that automatically apply the correct tension to change the shape of the lens so the image is in focus on the retina. In the camera, we must adjust the focus by moving the lens itself. Could we move the film back and forth and accomplish the same thing?

There can be two reasons for a person to be either near-sighted or far-sighted. The eyeball may be either flattened or elongated or the lens may be either too curved or too thin. When both defects occur in the eye they can either compensate for each other so the person is normal visioned or the defect can be intensified. A near-sighted person can either have too thick of a lens which would focus the image in front of the retina or the eyeball may be elongated which, again, would throw the focused image in front of the retina. Such a person would require some corrective lens which would diverge the light rays to some extent and cause the image to be focused on the retina. A concave lens will spread light rays out or diverge them so a near-sighted person would require some type of concave lens such as the plano-concave lens illustrated in Figure 4.

Figure 4.

Since the light rays are diverged in any type of concave lens, the image we see through a concave lens will appear to be smaller than it really is. On the other hand, we should be familiar with magnifying glasses which are convex in shape. With this information, we can easily determine whether another person is near sighted or far sighted by looking at print through his glasses. If the print is smaller the lens must be concave and the person must be near sighted. If the print is larger the lens must be convex and the person must be far sighted.

By using two lenses, we can make a telescope similar to the one that Galileo used for his observations in 1610. The two lenses we will use are called plano-convex and plano-concave. Using two lenses of this type, Galileo found that he could get a focused image that was enlarged when he had the two curved surfaces toward the object and the lenses were properly spaced in front of his eye.

## PROCEDURE

Place the double-convex lens in its holder on the meter stick 20 cm from the light source and move the screen back and forth on the stick on the other side of the lens until you can see the image of the source focused on the screen. How far must the screen be from the lens to get the image focused? Is the image right-side-up or inverted. Is the image enlarged?

Repeat the experiment with the lens 30 cm from the source. How far must the screen be from the lens now to get the image focused? After a certain distance from the lens is reached could the screen be left in one position and still have the image in focus no matter how far the object was moved away?

Place the plano-convex lens on the meter stick approximately 18 inches from the lamp with the curved side toward the lamp. Adjust the screen to get the best focus. Next, place the plano-concave lens between the plano-convex lens and the screen with the curved side toward the lamp. The plano-concave lens should be as close to the screen as possible. Remove the screen and observe the lamp image through the plano-concave lens. Keep your eye close to the plano-concave lens and adjust it for the best focus. (See Figure 5.) Is the image magnified? Is the image right-side-up or inverted?

Remove the supports from the meter stick and place the cheek piece on the end closest to the plano-concave lens. Take the arrangement to a window and focus it on a far away object. Could this be used as a telescope? Pick out an object to focus on and approximate the magnification over normal.

Place the plano-convex lens on the meter stick approximately 24 inches from the lamp with the curved side away from the lamp. Adjust the screen to get the best focus. Place the double-convex lens as far away from the screen as the distance between the screen and the lens in the second part of this experiment. Remove the screen and move the double-convex lens toward the plano-convex lens to get the best focus. See Figure 6. Take it to the window as before. Which arrangement makes the most satisfactory telescope? Why?

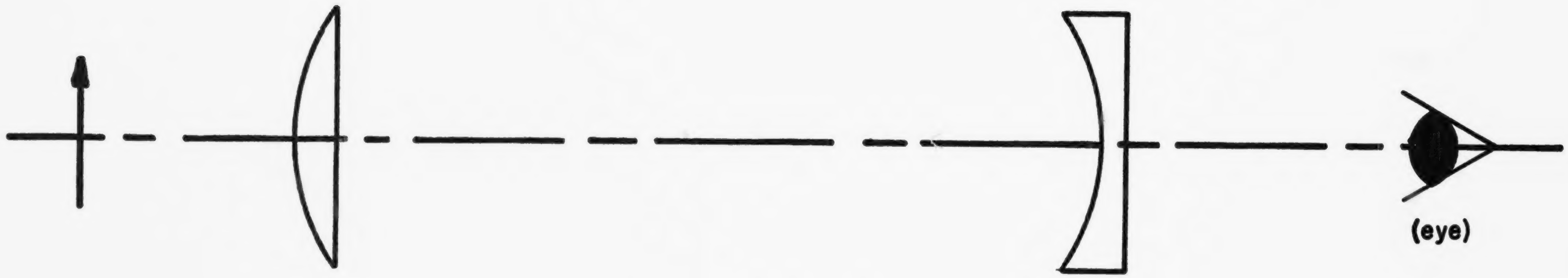


Figure 5.

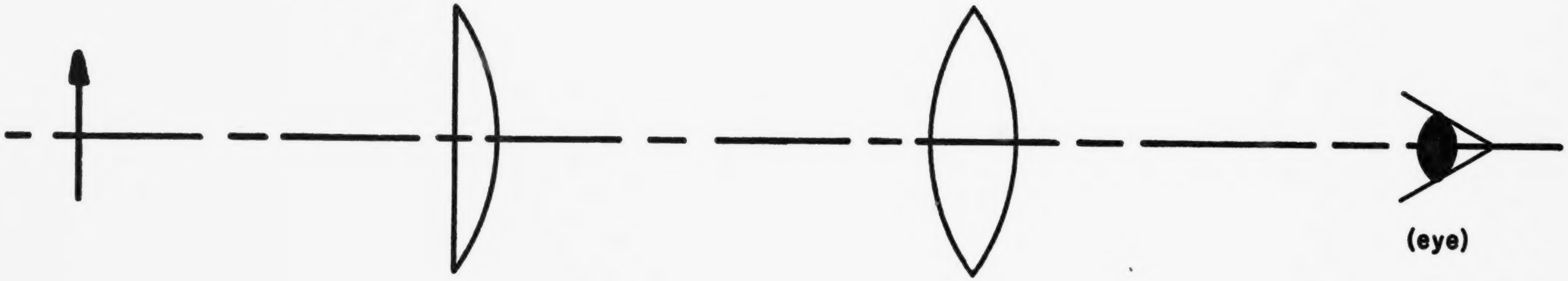


Figure 6.

## QUESTIONS

1. What type of corrective lens would a far-sighted person require?

2. What type of lens could a drop of water be compared to? Could we use it to magnify objects?

3. What is the greatest limitation to the use of lenses for magnification?

4. Planets can be magnified or enlarged by the use of telescopes but stars cannot be magnified. Why?

## EXPERIMENT
## 20

# RADIOACTIVITY

In 1896, a new physical phenomena was observed by Henri Becquerel. Particles were discovered to be emitted from different substances that could cause spots to appear on unexposed photographic plates and flashes of light to occur in other substances. Because these particles were radiated from the parent substance in a manner that was thought to be similar to heat radiation, the phenomena was referred to as radioactivity.

At first, the nature of the particles was not known, so the particles were named after the first letter of the Greek alphabet - $\alpha$ -particles (Alpha). Later,other particles of a different nature were discovered and these were named for the next letters in the Greek alphabet - $\beta$-particles (Beta) and $\gamma$ -particles (Gamma). Further investigation has revealed the nature of these particles. The $\alpha$ -particles are identical to atoms of helium that have had both of the electrons removed. The $\beta$ -particles have the same physical properties as electrons. The $\gamma$ -particles were found to be different from either of these in that they did not posses an electrical charge. They were finally found to have the same properties as the particle-like behavior of light, but of a much higher frequency or energy.

Radioactive particles are the result of the disintegration of the atoms in a material to form other kinds of atoms of different elements than the original. This disintegration takes place at a fixed rate for each kind of radioactive material. If there is a given amount of material, this fixed rate of disintegration says that, after a certain period of time, one-half of the material present will have disintegrated to form a new material. IT DOES NOT MAKE ANY DIFFERENCE AS TO HOW MUCH MATERIAL WAS ORIGINALLY PRESENT. This rate is called the half-life of the material. Thus, after one half-life, there will be one-half of the material remaining; after two half-lives, half of that will have disintegrated leaving one-fourth of the material; etc.

In order for a radioactive particle to be detected, it must react with some material by colliding with it. There are two general ways that these collisions can be detected. First, the radioactive particle may form an ion in the detecting material by knocking one or more electrons out of the atoms of the detecting material and the ions may be detected by either electrical or chemical methods. Second, the particle may raise the amount of energy in the electrons of the atoms without actually removing them from the atoms. When the electrons return to their previous states, they have to lose this energy, and they do this by emitting light that can then be observed. This second way of detecting radiation particles is called scintillation. We will see examples of ionization detectors in this experiment, but not scintillation as the amount of light emitted is very small and is very difficult to see without special equipment.

Because of the different natures of the three different kinds of radioactive particles, they may travel different distances through materials, $\alpha$ -particles, because of their relatively large mass and electrical charge, are the easiest to stop. $\gamma$ -particles, because they have neither a charge nor a rest mass, are the most difficult to stop in a material. $\beta$ -particles generally fall in between these other two kinds of particles.

Since the discovery of these three kinds of particles, other particles have been discovered that are even more difficult to detect than the $\gamma$ -particles. These particles have not been associated with previously known particles that are found by other than radioactive methods. Their nature is not completely understood by scientists as yet. Because of the extreme difficulty in detecting them, we will not attempt to work with them in this experiment.

## PROCEDURE

A simple cloud chamber can be made from a cylindrical plastic box. The bottom can be painted black to make the tracks visible. A dark felt band encircles the inside of the top of the chamber to be soaked with methanol. By placing the radioactive source near the bottom of the chamber and placing the chamber on a block of dry ice, fog tracks can be seen radiating from the radioactive source after a few minutes. To make the tracks more visible, a light may be shone through the side of the chamber. Are the tracks developed uniformly in all directions at a definite rate or do they seem to be developed randomly? Do you think particles are also being emitted upward and downward? Are all of the tracks the same length? What causes the tracks to end? Are you actually seeing a radioactive particle? If not, what are you actually seeing? Do you think there is only one type of radiation being emitted? Give your reasoning.

A Geiger-Müller tube has a gas in it and a certain voltage across it. When radioactive particles enter it, they ionize the gas in its track and make it easier for the voltage to cause current to pass through the tube. A meter or a speaker can record these pulses of current. Bring the G-M tube near a radioactive source. Are the pulses of current recorded at an even tempo or are they sporadic? Why are there fewer pulses when you move the G-M tube away from the radioactive source? Holding the G-M tube at a certain distance from the radioactive source, record the pulses for two minutes three different times. What conclusions can you draw? Test other sources with your G-M tube. How common is radioactivity?

Using different radioactive sources with the G-M tube the same distance from each source try to stop the radiation from reaching the tube by placing different obstacles between the radioactive source and the G-M tube. (Suggestions: various numbers of sheets of paper, different strips of metals.) Do some radioactive particles seem more difficult to stop than others? What does this suggest?

Observe pictures of fog tracks from cloud chambers taken while being subjected to strong magnetic fields. Some tracks curve in one direction but they have different curvatures. What does this suggest? Some tracks curve in opposite directions with the same curvature. What does this suggest? Some tracks curve in opposite directions with different curvatures. What does this suggest? Do any tracks go straight? What does this suggest?

## QUESTIONS

1. Why was radioactivity so late in being discovered?

2. Name three ways that radioactivity can be used for the benefit of mankind.

3. Why is radiation from radioactive sources dangerous?

4. Why is getting rid of radioactive wastes becoming a problem? How would you suggest getting rid of radioactive wastes?

## EXPERIMENT
## 21

## ROCKS AND MINERALS

The solid portion of the earth, called the geosphere by geologists, is composed of a wide variety of materials contained in a large quantity of different formations. By studying these materials, geologists can determine the past history of that region of the earth over many millions of years in some cases. Exploration, so far, has been limited to a very thin portion of the earth's 4,000 mile radius. This portion forms the outer surface of the earth, or what is called the earth's crust.

The materials of the earth that have been investigated thus far have been systematically classified according to their composition, origin, and physical characteristics. In this experiment, we will use this classification system in examining several examples of these materials. The materials are grouped first into classes of rocks, usually according to their method of formation. The chemical composition of a rock of a particular type may vary widely from sample to sample and is usually composed of a large number and variety of crystals that are called minerals.

Minerals are not defined in the same manner from one reference to another. For our purposes, we will define a mineral as a naturally occuring, nonorganic, crystalline material found in the earth. (Minerals that are collected for commercial purposes are called ores.)

Rocks are classified according to their origin as igneous, sedimentary, or metamorphic. Igneous rocks are formed by the cooling and solidifying of molten material. Sedimentary rocks are formed when erosion forces wear down existing rocks, and the small rock particles that result are deposited in layers (usually after being carried to another area by water). The lower layers are compressed by the newer layers above them and form rocks with characteristics that are often different from the original materials. Metamorphic rocks can be igneous, sedimentary, or a combination of igneous and sedimentary rocks that have been subjected to extreme heat and/or pressure (but not heated to the extent that the rock melted). Metamorphic rocks often retain the characteristics of the original rocks, but also show they have been changed by the existence of a different crystal structure or a change in color, hardness, or density.

Igneous rocks may be further classified by the manner in which they have cooled. When the molten rock, called magma, cools below the surface of the earth, the process takes a very long time and larger crystals of the minerals composing the material are allowed to form. The resulting rocks have a coarse texture, such as that found in the granites. When the rock cools below the surface of the earth, it is called an intrusive igneous rock. When magma is forced up to the surface of the earth, it is called lava. Lava cools much more rapidly than magma that cools below the surface of the earth. Furthermore, trapped gases are frequently released when the magma reaches the surface to become lava. Because the cooling time is so much shorter, the minerals have less time to form crystals and the resulting crystals are much smaller. In addition, the gases trapped in the material can cause the resulting rock to be very porous (or sponge-like) so the rock has a much lower density than it would have if it had cooled below the surface. Rocks that are formed by cooling lava are called extrusive igneous rocks.

Most sedimemtary rocks result from the accumulation and later consolidation of mud, clay, silt, sand, and shell fragments at the bottom of a body of water or from the precipitation of dissolved salts when a body of water dries up. Many sedimentary rocks contain ripples similar to those that can be seen forming at the bottom of lakes, seas, and oceans today. Sedimentary rocks are also the only types of rocks that contain the fossilized remains of previously living plants and animals. From the preservation of these features, it seems clear that sedimentary rocks form near the surface of the earth where heat and pressure are not great enough to distort the original structure of the materials. Sedimentary rocks often display the characteristics of the material from which they were formed and are, therefore, fairly easy to identify.

A characteristic of metamorphic rocks is that the minerals in such rocks tend to be arranged in parallel sheets, bands, and streaks called foliation. Sufficient heat has been applied to them in their formation that it sometimes becomes extremely difficult to determine their original formation. Such rock, at one time or another, became plastic due to heat and pressure and could bend and twist without being broken, although it never reached a molten state.

Because different kinds of rocks are formed near each other, it is occasionally difficult to fit a particular rock sample into a clearly defined category. For example, consider thick layers of sedimentary or igneous rocks that have been partially metamorphized. There is no definite boundary where we can say that all of the rock on one side of a line is the original rock type and on the other side all of the rock is metamorphic. Similarly, we sometimes have difficulty in separating igneous rocks into either intrusive or extrusive classifications. However, by studying the classical characteristics of certain types of rocks and minerals, we can gain a clearer understanding of the crust of the earth and the changes which have occurred and are continuing to occur.

In order to identify and classify rocks and minerals, we have to examine samples for certain characteristics, such as those given below. For different samples, certain of the characteristics will be much more important than others and some of the characteristics may not apply at all for the particular sample you are studying.

1) Color. Color is a useful property for some minerals, but a misleading one for others. Therefore, you should be very careful when using criteria of color as a basis for differentiating between samples of different rocks and minerals.

2) Streak. The streak of a rock is the color of the powder left when it is scratched on an unglazed plate. A thin layer of powder is more important than a thick one. If the streak of a rock is a different color than the color of the rock itself, this is a distinguishing property that should be noted.

3) Luster. Luster is a measure of the way the rock reflects light from its surface. Luster is divided into metallic and non-metallic. Rocks with a dark streak (see part 2) are generally metallic, while those with a light streak are generally non-metallic.

4) Iridescence. Iridescence is a change in the color or colors on the surface of the rock when it is subjected to light from different directions. An example of iridescence would be the changes in the colors of light reflected from a drop of oil in a pool of water.

5) Transparency. Transparency refers to whether or not the rock will transmit light. It is said to be transparent if objects can be seen through it, translucent if only diffuse light can be seen through it, and opaque if no light can be seen through it. Most rocks are opaque.

6) Specific Gravity. Recall the definition of specific gravity from an earlier experiment. For our purposes, it will be sufficient to determine whether the rock is light, medium, or heavy.

7) Hardness. Hardness of a rock is determined by whether or not it can be scratched by or scratches another object. In the table below, the higher the number, the harder the material. Thus, a glass plate can scratch calcite, but will be scratched itself by quartz. The "Practical Hardness Scale" refers to the materials that you will be using in the laboratory.

| Practical Hardness Scale | MOHS Hardness Scale |
|---|---|
| | 1 Talc |
| | 2 Gypsum |
| 2-1/2 Fingernail | |
| 3 Copper Penny | 3 Calcite |
| | 4 Fluorite |
| | 5 Apatite |
| 5-1/2 Glass Plate | |
| | 6 Potassic Feldspar |
| | 7 Quartz |
| | 8 Topaz |
| | 9 Corundum |
| | 10 Diamond |

8) Structure. A description of the structure of a rock is a description using only one or two words - such as single crystal, crystalline aggregate ( a group of crystals bound together), or amorphous (no crystal structure).

9) Cleavage. The tendency of certain minerals to split or break off in well-defined layers is known as cleavage. Some, but not all, of the crystalline rocks exhibit cleavage. If the rock does not have a crystalline form, it cannot exhibit cleavage.

10) Fracture. Fracture is the ability of the rock to break along lines and directions other than those on which cleavage exists. Since amorphous rocks have no cleavage, they tend to fracture easily.

11) Tenacity. Tenacity refers to the tendency of minute particles of the rock to cling together when outside forces are being exerted to try to separate them.

12) Effervescence. Effervescence refers to the way that the rock reacts to dilute hydrochloric acid on its surface.

13) Magnetism. A small number of rocks are attracted to a magnet.

14) Feel. - such as whether the surface seems soapy, smooth, or rough, etc. when touched.

15) Odor. The smell of the rock - usually after it has been moistened or broken.

16) Taste. Usually determined when the rock can be dissolved in water.

## PROCEDURE

Each table has a box of rocks and minerals which are classified as to their name and the type of rock they were found in. Examine them carefully and learn how to distinguish which class of rock a particular sample would belong to merely by examining its characteristics.

Each table contains a magnet, a glass plate, and an unglazed plate together with several samples of rocks that have been labeled. For each of these samples, investigate the different characteristics according to the definitions given earlier and record your observations.

## QUESTIONS

1. If heavy flows of lava poured out over layers of sedimentary rock, what effect do you think this would have on the sedimentary rock?

2. To trap oil and gas underground and not let it escape, nature must provide a "cap" rock over the oil deposit. What type of rock would this "cap" rock most likely be? How could it be formed?

3. How does the difference between the Atlantic coastal region and the Pacific coastal region help us in determining the age of the Rocky Mountains in comparison with the Appalachian Mountains?

4. Give two methods by which limestone may be formed. What type of rock is limestone? How does marble differ from limestone?

5. What are some identifying characteristics of granite?

6. How could you distinguish granite from felsite?

7. How could you distinguish quartz from calcite?

APPENDIX

## CONVERSION TABLES

### LENGTH

| CGS | MKS | Equiv. |
|---|---|---|
| 1 cm | = $10^{-2}$ m | = 0.3937 in. |
| $10^{2}$ cm | = 1 m | = 39.37 in. |
| $10^{5}$ cm | = $10^{3}$ m | = 1 km |
| $10^{-4}$ cm | = $10^{-6}$ m | = 1 |
| $10^{-8}$ cm | = $10^{-10}$ m | = 1 A |
| 2.54 cm | = 0.0254 m | = 1 in. |
| $1.61 \times 10^{5}$ cm | = 1,609 m | = 1 mile |

### VOLUME

| CGS | MKS | Equiv. |
|---|---|---|
| 1 $cm^3$ | = $10^{-6}$ $m^3$ | = 0.061 $in^3$ |
| $10^{6}$ $cm^3$ | = 1 $m^3$ | = 35.31 $ft^3$ |
| 16.39 $cm^3$ | = $1.639 \times 10^{-5}$ $m^3$ | = 1 $in^3$ |
| $2.832 \times 10^{4}$ $cm^3$ | = 0.02832 $m^3$ | = 1 $ft^3$ |
| $3.785 \times 10^{3}$ $cm^3$ | = $3.785 \times 10^{-3}$ $m^3$ | = 1 gal. |
| $10^{3}$ $cm^3$ | = $10^{-3}$ $m^3$ | = 1 liter |

### MASS

| CGS | MKS | Equiv. |
|---|---|---|
| 1 gm | = $10^{-3}$ kg | = $2.205 \times 10^{-3}$ lb |
| $10^{3}$ gm | = 1 kg | = 2.205 lb |
| 453.6 gm | = 0.454 kg | = 1 lb |
| $1.46 \times 10^{4}$ gm | = 14.59 kg | = 1 slug |

If you need to use other tables such as densities, linear expansions, specific heats, etc., it is suggested you first try locating them in the *Handbook of Chemistry and Physics*.

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